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

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1. Introduction

Acoustics and Vibration Metrology Division of the NMIJ is responsible for Acoustics, Ultrasound and Vibration measurement standards in Japan. We have two sections, Acoustics and Ultrasonics Section and Vibration and Hardness Section.

Acoustics and Ultrasonics Section has two groups. One is responsible for precise acoustic measurement technology and metrology, covering audible sound, airborne ultrasound and infrasound. These fields are closely related to human hearing, noise pollution and safety evaluation. Another group is responsible for ultrasonic measurement techniques and metrology, such as ultrasonic power standard, ultrasonic pressure standard and ultrasonic field measurement. These measurement techniques are related to the medical diagnostics, treatments, and industrial applications.

Vibration and Hardness Section carries out research on vibration acceleration standards, hardness standards and material impact strength standards necessary to ensure the safety and quality control of transport equipment and structures. Hardness in microstructure, advanced vibration measurements and ultrasound measurements are also investigated to support next-generation industry.

2. Acoustics

<u>Activities after last CCAUV meeting</u>

(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 [1].

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

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

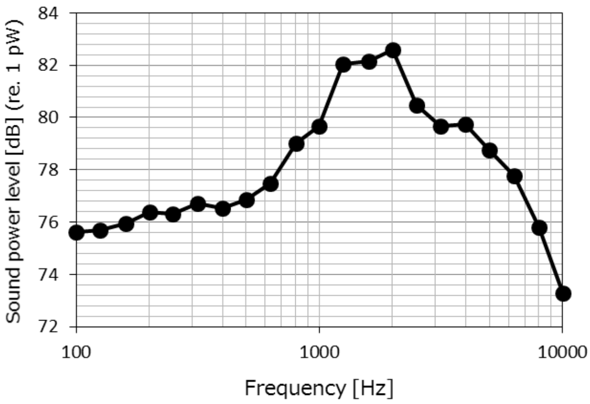


Fig. A2: Sound power level of RSS determined by our calibration system (Brüel and Kjær Type 4204)

such background, we NMIJ planned to start the calibration service for RSSs until 2014, and have been developed the RSS calibration system [2].

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 calibration frequency range is from 100 Hz to 10 kHz. **Fig. A2** shows an example of sound power level of RSS determined by our system under development. After the start of calibration service, we may expand the frequency range, covering from 50 Hz to 20 kHz by considering the further needs for the calibration.

(2) Calibration service for multifunction sound calibrators

NMIJ started the calibration service of multifunction sound calibrators in October 2013 for periodic test of sound level meters etc. They were added to the calibration service of sound calibrators, covering frequency range from 31.5 Hz to 16 kHz (**Fig. A3**). The quantity to be calibrated is sound pressure level only. The equivalence of the calibration results among NMIs will be confirmed by the result of APMP.AUV.A-S1. (Note: The final report of APMP.AUV.A-S1 is in progress.),

(3) Research works

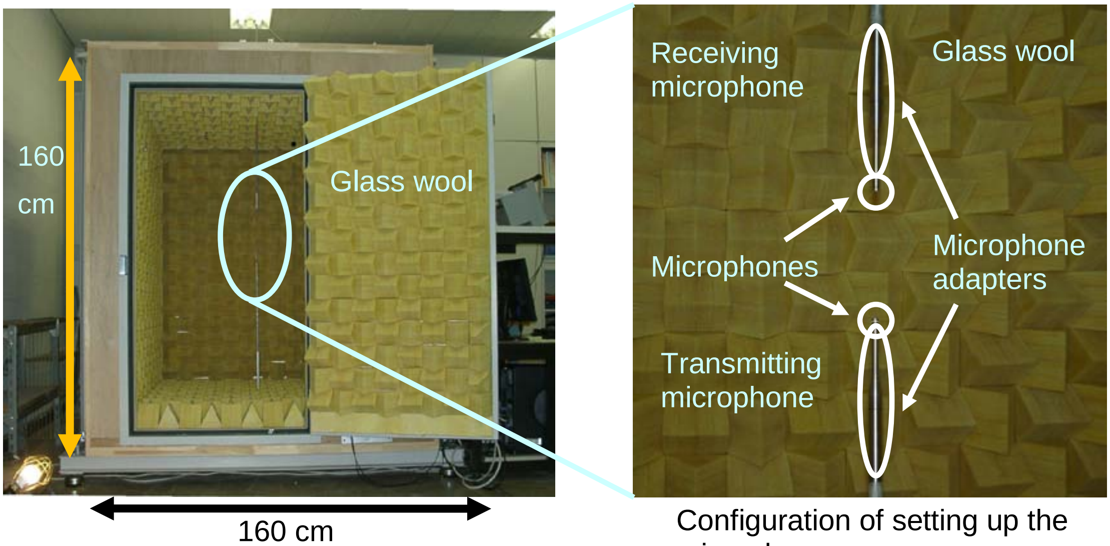
The free-field sensitivity level calibration service for airborne ultrasound by the reciprocity technique was started in 2009. Since then we have improved the calibration system to decrease the measurement uncertainties [3-5]. Practically, WS3 microphones are used for the measurement of audible sound as well as airborne ultrasound, while the calibration service of WS3 microphones has

not been provided in audible frequency range yet. At audible frequencies, the free-field sensitivity level calibration is made in compared with LS2 microphones in an anechoic room. We will start the calibration service by the next year. Other research activity includes examining the consistency of free-field sensitivities among LS1P and LS2P microphones. This research has been continued in these years.

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 (20 Hz to 20 kHz). Type WS3 microphones for audible frequency range will be added as one of the calibration items.
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. In 2013, calibration frequency range was expanded and now covers from 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. A4**) 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. A5**), Calibration frequency range of LS1P microphones is from 1 Hz to 20 Hz. This standard is essential for low frequency noise analysis and evaluation.



160 cm
Anechoic box

Configuration of setting up the
microphones

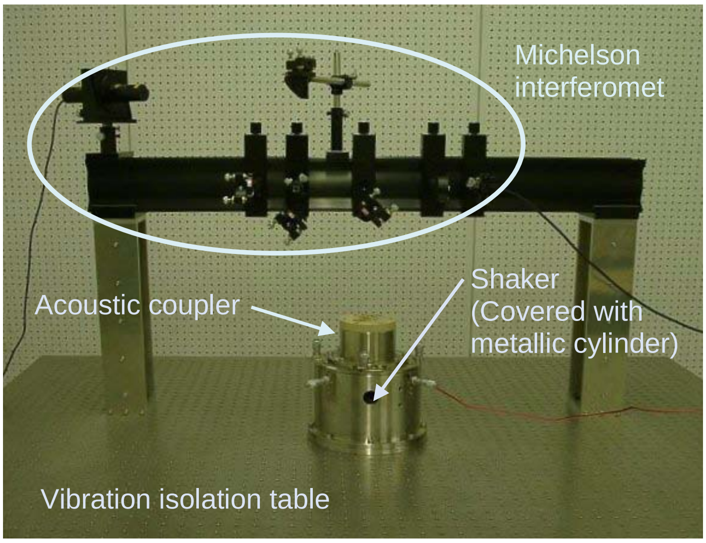


Fig. A5: "Laser pistonphone" which composes the microphone calibration system for infrasound.

Key comparisons and peer review

NMIJ's participation in the international key comparison, CCAUV.A-K5 was delayed due to the earthquake but we finally completed calibration in August 2012. We would like to express our gratitude to the pilot lab., NPL and especially to Richard Barham and Janine Avison.

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 year.

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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 which was dropped to floor by the earthquake has been recovered completely (**Fig. U1).** The specifications of the system have been checked and we restarted calibration services. 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 has been developing 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, and **Fig. U3** shows a schematic top view. 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 at 1 MHz. In addition, we expand the frequency range for the validation of the calorimetric calibration from 1 MHz to 3 MHz as shown in **Fig. U4**. The deviations between ultrasonic power measurement using calorimetric and RFB methods are within 5 %.

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 frequency range up to 40 MHz by using laser interferometry. For lower frequencies from 100 kHz to 1 MHz,

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

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

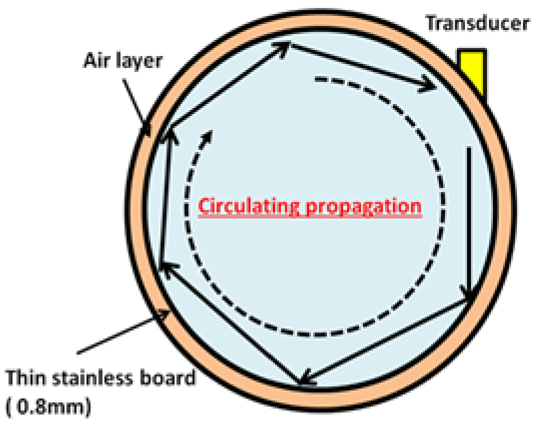
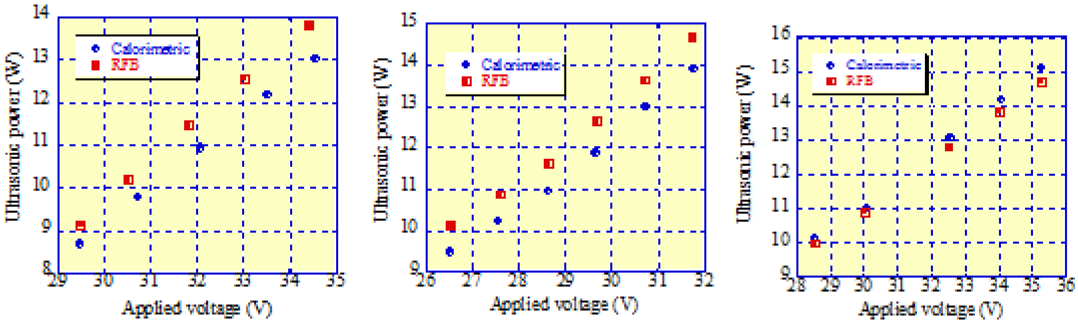


Fig. U3: Top view of the water bath.



1 MHz 2 MHz 3 MHz

Fig. U4: 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.

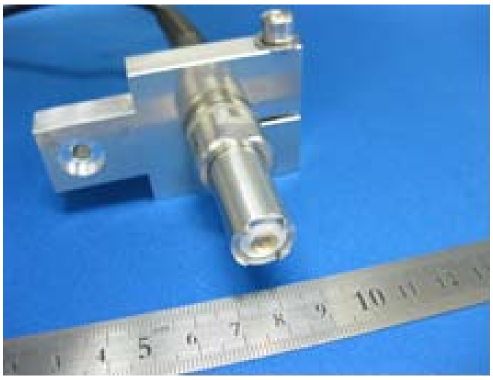


Fig. U5: A photograph of fabricated 40 MHz ultrasonic transducer with 2 mm diameter active element.

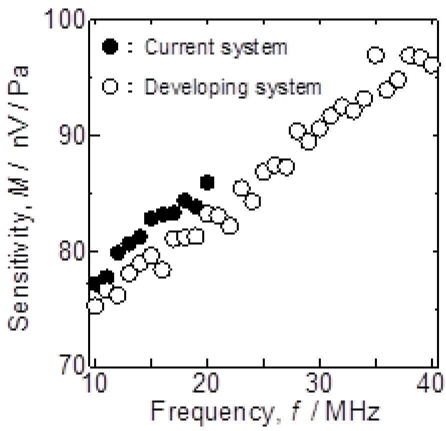


Fig. U6: Measured hydrophone sensitivity up to 40 MHz.

hydrophone sensitivity calibration will be provided using reciprocity technique. The expansion of frequency ranges is scheduled to be finished within one or two years.

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. U5.** And for the practical reason, it should have wideband frequency characteristics. We are developing this type of transducers by using PVDF whose nominal active element diameter is 2 mm. As the result, we achieved the calibration up to 40 MHz as shown in **Fig. U6**. 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

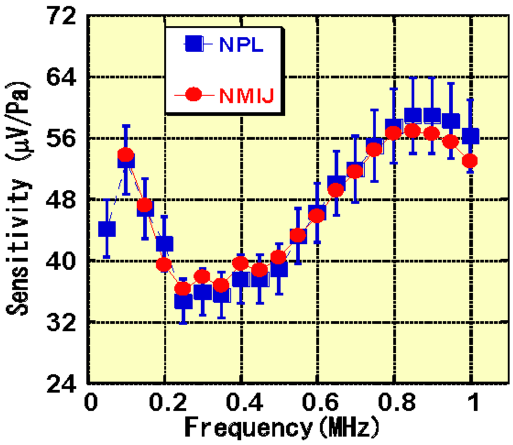


Fig. U7: Measured hydrophone sensitivity between 1 kHz and 1 MHz by reciprocity technique. The measured sensitivity is compared with the calibration chart by NPL.

calibration system at frequencies of 10–20 MHz.

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. A calibration result using this system was validated in comparison with that in NPL as shown in **Fig. U7**. We are also constructing the comparative calibration system for this frequency range.

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.

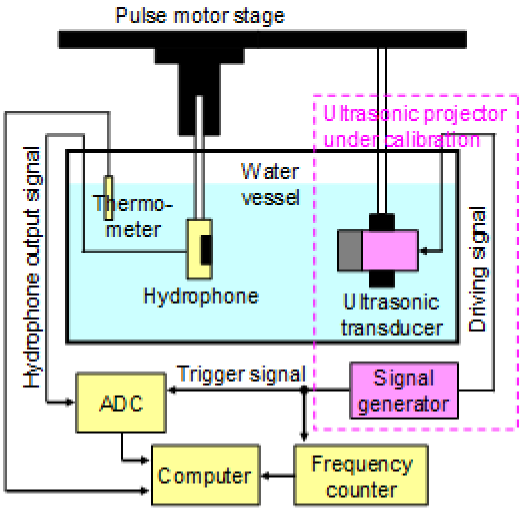


Fig. U8: A block diagram of the measurement system for ultrasonic field parameters.

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4. Vibration and acceleration standards

NMIJ has developed five calibration systems for the national standard of vibration and shock acceleration [1]-[13]. The four systems for vibration acceleration 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) [14]. The system for shock acceleration is in compliance with ISO 16063-13 (Methods for the calibration of vibration and shock transducers. Part 13: Primary shock calibration using laser interferometry) [15]. They are classified for their calibration range as follows.

- System 1; Very low frequency range: 0.1 Hz – 2 Hz. (CMC not published yet)

Fig. V1 System 1: 0.1 Hz to 2 Hz

- System 2; Low frequency range: 1 Hz – 200 Hz. (CMC not published yet for 1Hz to 40 Hz)

Fig. V2 System 2: 1 Hz to 200 Hz

- System 3; Middle frequency range: 20 Hz – 5 kHz. (CMC already published except for 20 Hz to 40 Hz)

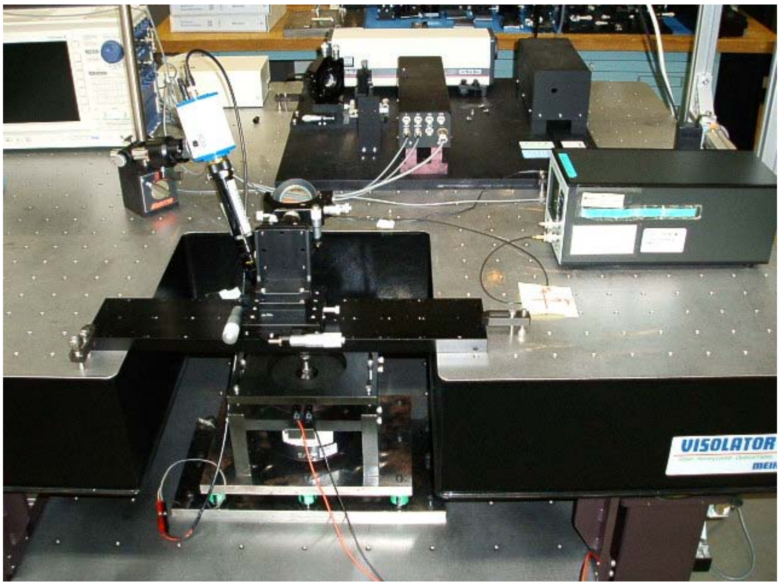

Fig. V3 System 3: 20 Hz to 5 kHz

- System 4; High frequency range: 5 kHz – 10 kHz. (CMC not published yet)

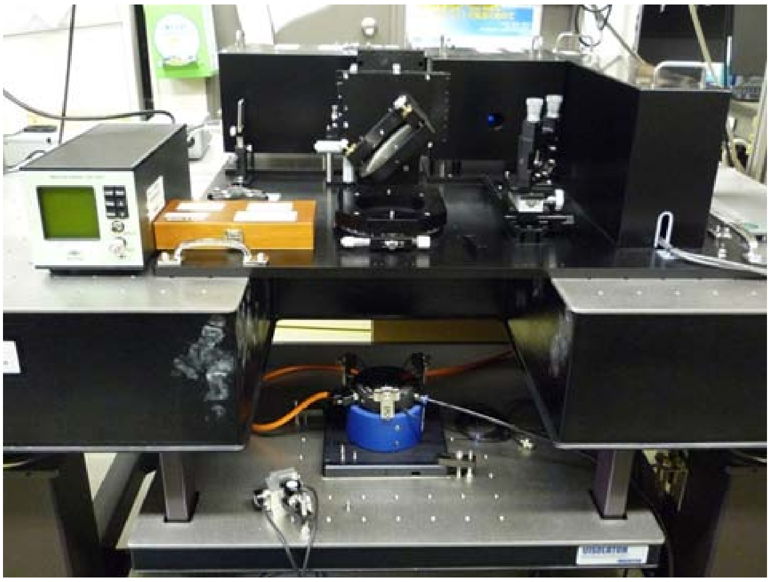

Fig. V4 System 4: 5 kHz to 10 kHz

- System 5; Acceleration amplitude range: 200 m/s^2 – 5000 m/s^2. (CMC not published yet)

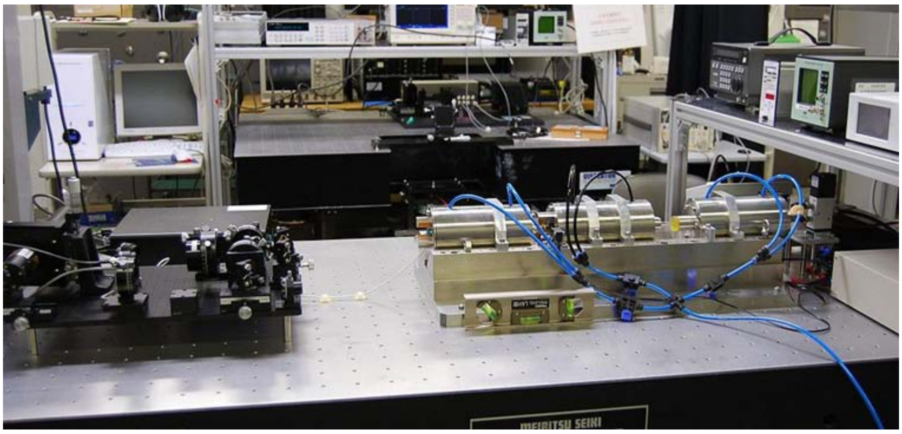

Fig. V5 System 5: Shock acceleration calibration system

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. The motion of vibrator is horizontal direction. Applicable acceleration range lies from 0.03 m/s^2 to 10 m/s^2 [3].

System 2 is realized by a combination of Michelson laser interferometer for fringe-counting method in compliance with ISO 16063-11 and an electro dynamic vibrator with moving part supported by beam. The vibrator can generate rectilinear motion with horizontal or vertical direction by changing its posture. The maximum stroke is 80 mm.

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 and an electro dynamic vibrator with moving part supported by beam [1], [2]. The motion of vibrator is vertical direction.

System 4 is realized by a combination of modified homodyne Michelson laser interferometer and an electro dynamic vibrator with air-borne slider. The motion of vibrator is vertical direction. To obtain high resolution laser interferometer for displacement measurement in vibration, we developed the modified Michelson type laser interferometer with a multifold optical path and signal processing algorithm which can be named multiple Sin-approximation method [4]-[6]. This system has realized a calibration capability within an expanded uncertainty of 0.8 %.

System 5 is the shock calibration system for high acceleration amplitude from 200 m/s^2 to 5000 m/s^2 with the expanded uncertainty of 0.6 % (k=2) [11]. The shock exciter employs porous air bearings for supporting shock generation parts [9]. The equivalence of shock calibration between

NMIJ and three private laboratories was already confirmed [10], and the shock calibration service started from 2010. In order to calibrate shock sensitivity more precisely, the investigation has been done together with PTB [17]. The calibration range will be extended to the peak acceleration range of 50 m/s^2 to 10000 m/s^2 in this fiscal year.

Technical competence in four systems from system 1 to 5 has been confirmed by peer reviews in 2002, 2007 and 2013.

Fig. V6 Transportable calibration equipments

Fig. V7 Digital demodulator for laser vibrometer standard

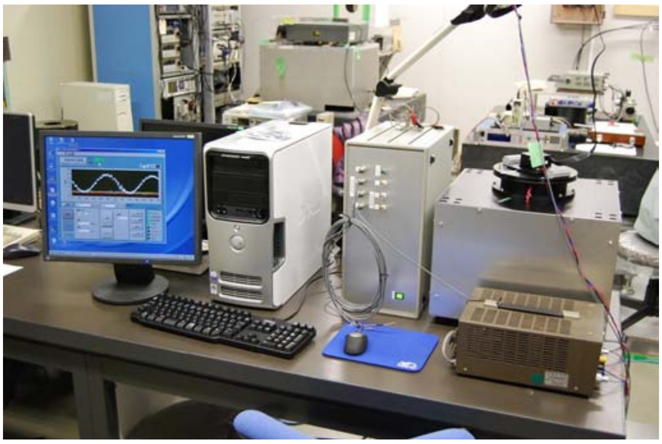

Fig. V8 Angular velocity calibration system under development

Now, NMIJ has been developing transportable calibration system for on-site calibration as shown in **Fig. V6** [18]-[20]. 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. V7**[21], [22], [23]. Beside, an angular velocity calibration system from 6 deg/s to 300 deg/s is being developed with the use of a self-calibratable rotary encoder (selfA) as shown in **Fig. V8**.

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. Each calibration result among participated NMIs will be compared and linked to the CIPM comparison, CCUAV.V.K-1 in 2001. In the first circulation between participants in 2009, remarkable deviation among the measurement results for DUT was observed in high frequency range. The second circulation was carried out under revised technical protocol, in which the calibration for back-to-back accelerometer is carried out without mass loading. But, in the second circulation, the remarkable deviation between the measurement results for initial measurement and interim check was observed in whole frequency range. Therefore, the technical protocol was revised again, in which the transportation method is acceptable only for hand-carry. The third circulation was completed and the draft B reporting is in progress.

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