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 standards, ultrasonic field measurements and other related measurement techniques. 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 investigated to support next-generation industry.

Huge earthquake and tsunami hit the north east area of Japan on 11th March 2011. More than 20,000 persons were killed or still missing. The NMIJ/AIST also attacked by strong earthquake, and many facilities including AUV measurement systems were seriously damaged. In addition, we were forced to become restricted the research activities due to electrical power shortage caused by the nuclear power plants damages. We would like to express gratitude to all persons who kindly gave help to our historical disaster. We have gradually recovered out from difficult situations.

In this report, we have referred to the damages of AUV measurement facilities in addition to research reports.

2. Acoustics

A huge earthquake hit in Japan on March 11, 2011 and caused damage to our measurement facilities. Major damages were the anechoic room in NMIJ. The anechoic room leaned at an angle due to subsidence of the base supporting the anechoic room. In addition, the door of the anechoic room became unable to be opened or closed (**Fig. A1**). The repair works were finished in October. All the calibration services are in operation now.

Fig. A1 Damaged door of the "large anechoic room" of NMIJ.

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

1) Primary calibration of pressure sensitivity level of laboratory standard microphones (LS1P & LS2P) by using the pressure reciprocity technique.
2) Primary calibration of free-field sensitivity level of laboratory standard microphones (LS1P & LS2P) by using the free-field reciprocity technique.
3) Comparative calibration of free-field sensitivity level of working standard microphones. 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.
5) Determination of sound pressure level radiated from sound calibrators. Calibration frequency range will be expanded within a few years (31.5 Hz to 16 kHz).
6) In 2009, the microphone calibration system for high frequency range (air-borne ultrasound, 20 kHz to 100 kHz) by using the free-field reciprocity technique in the compact anechoic chamber has been established. This standard is essential for human safety evaluation and for testing equipment which radiates air-borne ultrasound (**Fig. A2**).
7) In 2011, “Laser pistonphone”, the microphone calibration system for low frequency range (infrasound, 1 Hz to 20 Hz), has been established and the calibration service was started this November. This standard is essential for low frequency noise analysis and evaluation. (**Fig. A3**).
8) Sound power level standard is going to be provided within a few years by developing the calibration system of reference sound sources. This standard ensures reliable noise

measurement of mainly office and home electric appliances.

9) Other research activity includes examining the consistency of free-field sensitivities among LS1P and LS2P microphones.

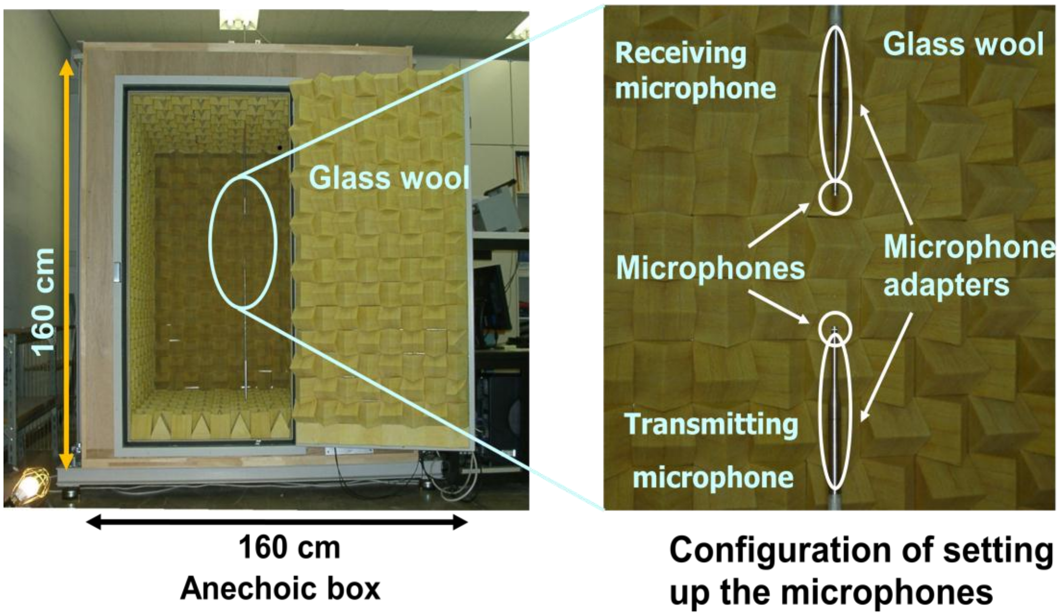

Fig. A2 Compact anechoic chamber used for the calibration of airborne ultrasound by the reciprocity technique.

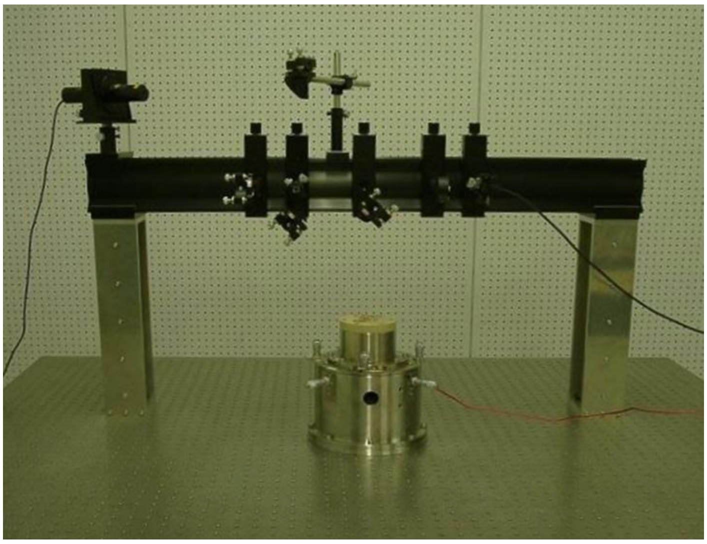

Fig. A3 "Laser pistonphone" which composes the microphone calibration system for infrasound.

<u>Key comparisons and peer reviews</u>

Schedules in 2011 were changed owing to the earthquake. NMIJ participates in the international key comparison, CCAUV.A-K5. Calibration period assigned to NMIJ has been re-scheduled in April 2012 (this schedule has been arranged again). Technical competence in the calibration system will be confirmed by peer reviews in 2012. It was initially planned within 2011.

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) Hydrophone sensitivity

Fortunately, measurement systems of hydrophone sensitivity and of ultrasonic field parameters described in the next section were not damaged by earthquake. The calibration service and research activity, however, were halted for three months during summer season by electrical power shortage.

The primary calibration system for sensitivity of the standard membrane hydrophone (CPM04, Precision Acoustic Ltd.)" by using the laser interferometry has been established in 2005. The frequency range of the calibration is 0.5 MHz to 20 MHz. Simultaneously, we have 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 0.1 MHz to 1 MHz, hydrophone sensitivity calibration will be provided by reciprocity calibration. The expansion of frequency ranges is scheduled to be finished within two or three years.

We are developing new type of an air-backed (hollow structure) pellicle for primary calibration of hydrophone sensitivity by laser interferometry. **Fig. U1 (a) and (b)** shows the comparison between the conventional and the air-backed pellicles. The air-backed pellicle is composed by very thin PET film and glass, and there is thin air layer between them. In the case of the conventional method, the ultrasound is transmitted in to the pellicle, on the contrary, ultrasound is reflected at the air-backed pellicle. The features of the air-backed pellicle are as follows;

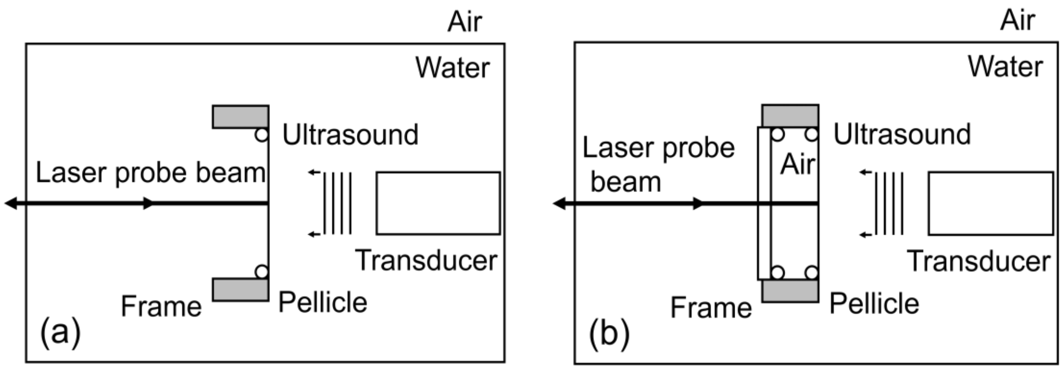

Fig.U1 (a) Conventional "transmission" method.

Fig.U1 (b) Developed "reflection" method with an air-backed (hollow structure) pellicle.

1) It is not required corrections for acousto-optic effect.
2) The vibration amplitude of the air-backed pellicle is almost twice that of the conventional pellicle, consequently, the sensitivity can be improved.

Fig. U2 shows the ratio of the sensitivity of hydrophone measured by using two types of pellicles. The difference of the measured sensitivities is within 2 %, and estimated uncertainty is 6 % ~ 9 %.

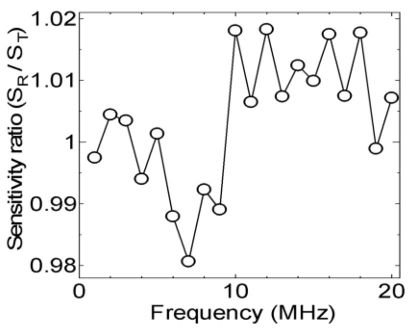

Fig. U2 Ratio of the measured sensitivity of a membrane hydrophone by two kinds of pellicles.

This result shows that "air-backed pellicle" will be available for hydrophone sensitivity measurement. We are going to replace conventional system with new one including "air-backed pellicle" in 2014, and calibration service up to 40 MHz will be started.

We are also developing the hydrophone sensitivity calibration system whose frequency range is 100 kHz to 1 MHz by reciprocity technique according to IEC 62127-2 and IEC 60505. This calibration system will be finished in 2012.

2) Ultrasonic field parameters

Recently, some of the Japanese manufacturers of ultrasonic equipments often requested us to measure the ultrasonic field parameters, such as I_{SPTA}, I_{SATA}, and p_R, which are closely related to the human safely. So, we have started the calibration service in 2007. Uncertainties of I_{SPTA}, I_{SATA}, and p_R are as follows (95 % level of confidence);

I_{SPTA}: 7 % ~ 10 %

I_{SATA}: 14 % ~ 20 %

p_R :14 % ~ 21 %

3) Ultrasonic power

The radiation force balance system of NMIJ was dropped to floor by the earthquake as shown in the **Fig. U3.**

Fig. U3 Dropped RFB system (Photographed immediately after the earthquake)

A thin electrical line in the magnet coil in the electrobalance was cut by the shock of drop. This electrobalance is a product of Cahn Instruments, a company of United States and has already been end of life. For some complicated reasons of the companies and the Japanese agency, very long period was required until starting repair. The repair was started the beginning of November at Karlsruhe in Germany. If everything goes smoothly, we will be able to restart ultrasonic power measurement at January or February.

NMIJ is participating in key comparison of ultrasonic power, CCAUV.U-K3. The original schedule of measurement at NMIJ was July 2011. But, by this damage, measurement schedule of NMIJ for CCAUV.U-K3 has been postponed. New schedule has not been fixed.

The primary standard of ultrasonic power by using the radiation force balance (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 ranges are as follows;

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

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

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

Developments of ultrasonic measurements and standards

Now, we are developing some of new ultrasonic measurement techniques which are applied for the purpose of HITU (High Intensity Therapeutic Ultrasound). In this development, however, we need "primary ultrasonic power measurement system" for checking the measured ultrasonic power by calorimetric system. By this reason, this work has been also halted since the earthquake.

1) High ultrasonic power measurement by using calorimetric method

This development needs the primary standard which was damaged by the earthquake as mentioned above. This development has been halted after the earthquake. The situations described here are as same as the previous report.

Ultrasonic high power standard has been developing by using “calorimetric method” with water as heating material**.** We have already achieved ultrasonic power measurement up to 100 W by this method. **Fig U4** shows a block diagram of the calorimetric method. In this measurement, water bath is one of the important key elements. We have developed “free field” water bath. **Fig. U5** shows the photograph of the water bath, and **Fig. U6** shows a schematic top view.

Fig. U5 a "free field "water bath.

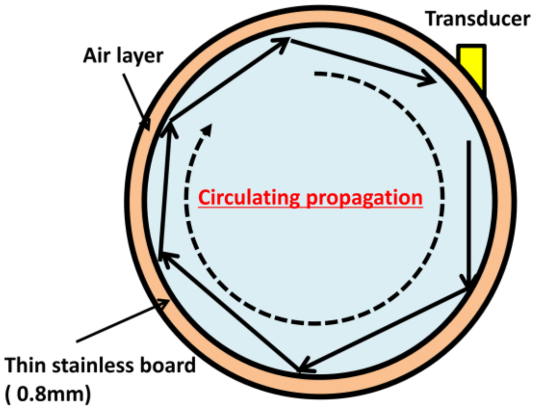

Fig. U6 Top view of the water bath.

The radiated ultrasound repeats reflections at the water bath wall, and finally, circulates one-way in the water bath. The measured ultrasonic power as a function of oscillator voltage is shown in **Fig. U7**. Up to 25 W, the measured power agreed with those measured by RFB method within 10 % ~ 15 %.

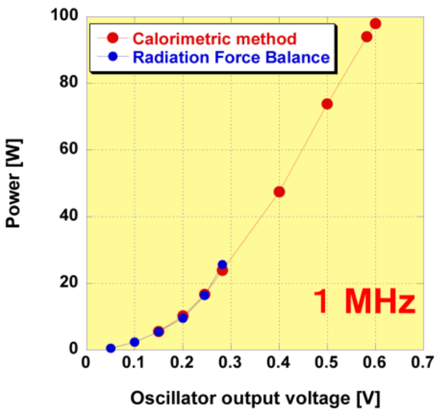

Fig. U7 Measured ultrasonic power by radiation force balance and calorimetric method up to 100 W, 1MHz.

2) Quantitative measurements for cavitation generation.

In near future, a cavitation sensor will become one of the important tools used for HITU. But at the present stage, quantitative measurement technique of cavitation has not been provided for users.

The purpose of this study is to develop quantitative measurement technique of cavitation generation, and to provide measurement tools for end-users. Our investigation is based on the cavitation sensor proposed by NPL. To evaluate the ability of quantitative measurement of the amount of cavitation, we have tried to compare the BIV (Broadband Integrated Voltage) with some conventional measured values, such as OH radical generation and sonochemical luminescence. Also, spatial distribution of cavitation generation in water vessel was measured by BIV. **Fig. U8** shows schematic figures and photographs of cavitation sensors fabricated at NMIJ. **Fig. U9 s**hows a relationship between the amounts of OH radical generated by cavitation and BIV. From this experiment, it is found that the BIV is almost proportional to the OH radical radiations. **Fig. U10** shows the relationship between input voltage to transducer and sonochemical luminescence (count of photons), BIV also plotted in the figure. Both sonochemical luminescence and BIV begin to increase at 60 V. These experiments results suggested that the BIV denotes the amount of cavitation generation quantitatively. **Fig. U11** shows the variation of BIV and acoustic pressure with position across the centerline of the water vessel. As the results, the peak position of BIV and acoustic pressure were different along the horizontal direction. Though acoustic pressure showed a peak at the center position, BIV of this position was small. The peaks of BIV were generated at both sides of sound pressure peak. The reason was that cavitation bubbles were not existed at center position because the cavitation bubbles were flowed by acoustic streaming toward the water surface. BIV will be more accurate measurement method of spatial distribution of cavitation generation compared to the acoustic pressure.

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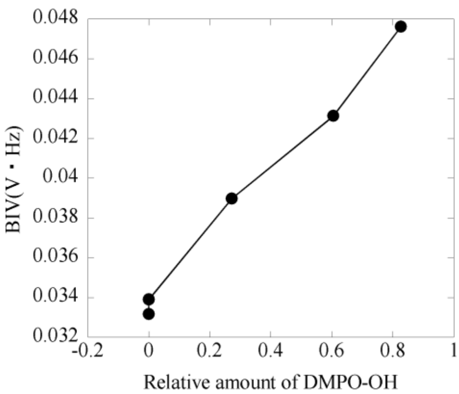

Fig. U9 Relationship between the amount of DMPO-OH generated by cavitation and BIV.

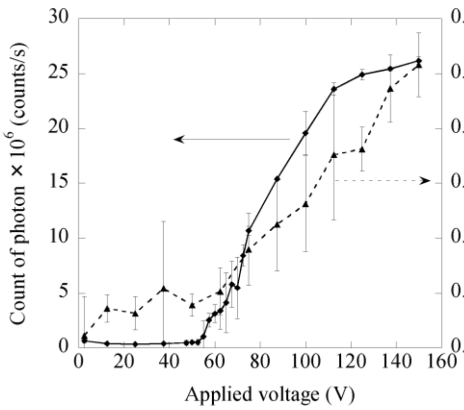

Fig. U10 Relationship between BIV and sonochemical luminescence as a function of

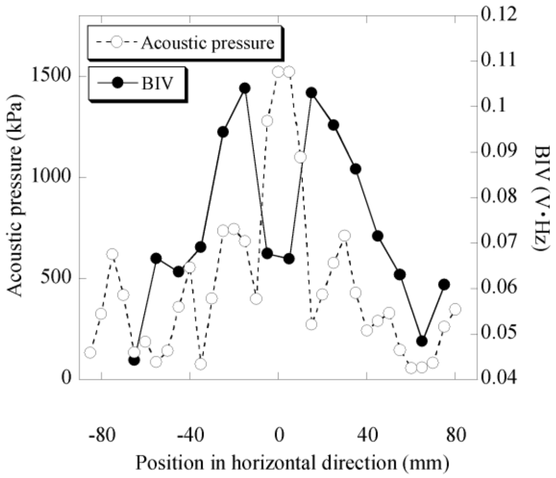

Fig. U11 Variations of BIV and acoustic pressure along the centerline of water vessel.

Then, a cavitation sensor with high spatial resolution has been fabricated as shown in **Fig. U12**. By using this sensor, spatial distribution of generated cavitation in standing wave field was measured. The schematic figure of the water vessel for experiment is shown in **Fig. U13**. Frequency of emitted ultrasound from the Langevin transducer was 150 kHz, namely, the half of wavelength of ultrasound in water is about 5 mm. The cavitation sensor was scanned along with the vertical axis on the center of Langevin transducer whose diameter is about 40 mm. The measured spatial distribution of BIV is shown in **Fig. U14**. As shown in this figure, periodical peaks with 5 mm separation was observed near the water surface. **Fig. U15** is the photograph of sonochemical luminescence (SCL) observed from the side of the water vessel. From SCL photograph, the spatial distribution of cavitation near the water surface is periods of 5 mm spacing and it is correspond to the result of BIV distribution shown in **Fig. U14**.. From these results, cavitation sensor with high spatial resolution can be used for the measurement of spatial distribution of generated cavitation.

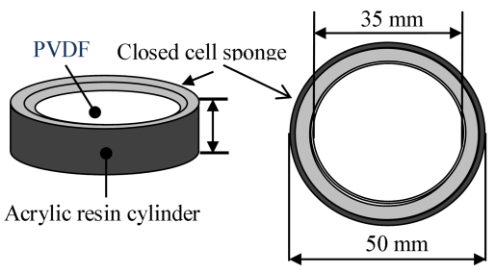

Fig. U12 A structure of cavitation sensor with high spatial resolution.

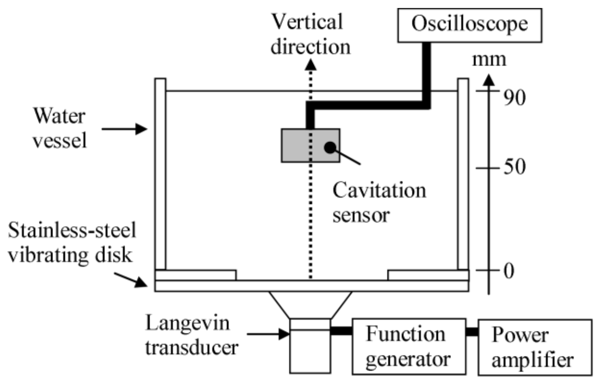

Fig. U13 A Schematic figure of water vessel for cavitation experiments.

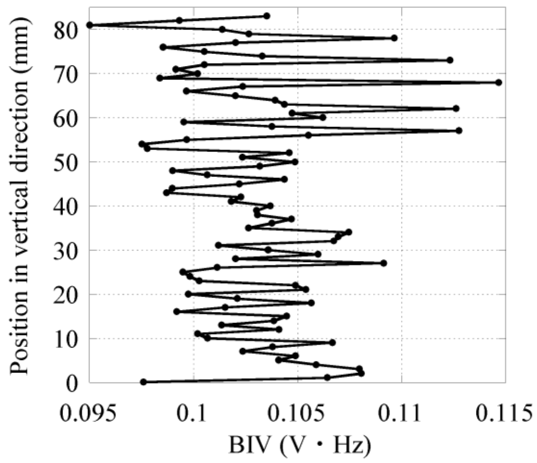

Fig U14 Measured BIV by scanning the cavitation sensor along with the center axis of the Langevin transducer, at the frequency of 150 kHz.

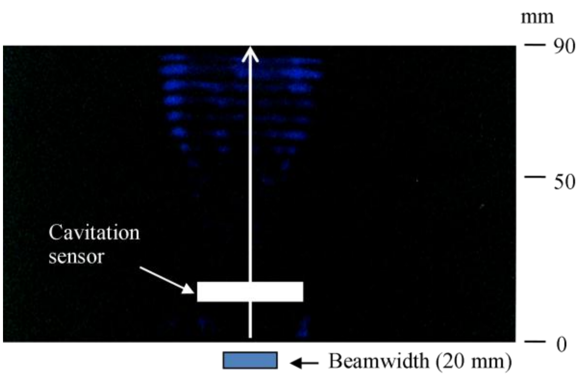

Fig. U15 Photograph of sonochemical luminescence observed from the side of the water vessel at the frequency of 150 kHz.

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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)

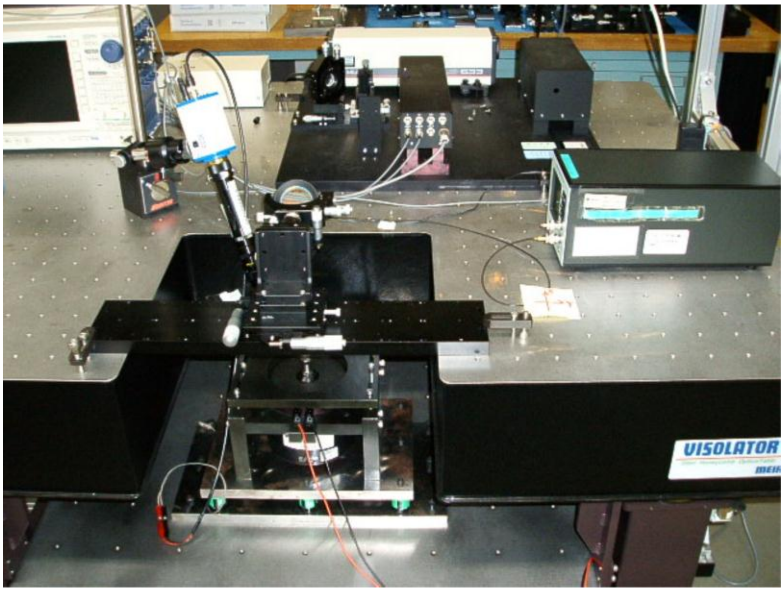

Fig. V3 System 3: 20 Hz to 5 kHz

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

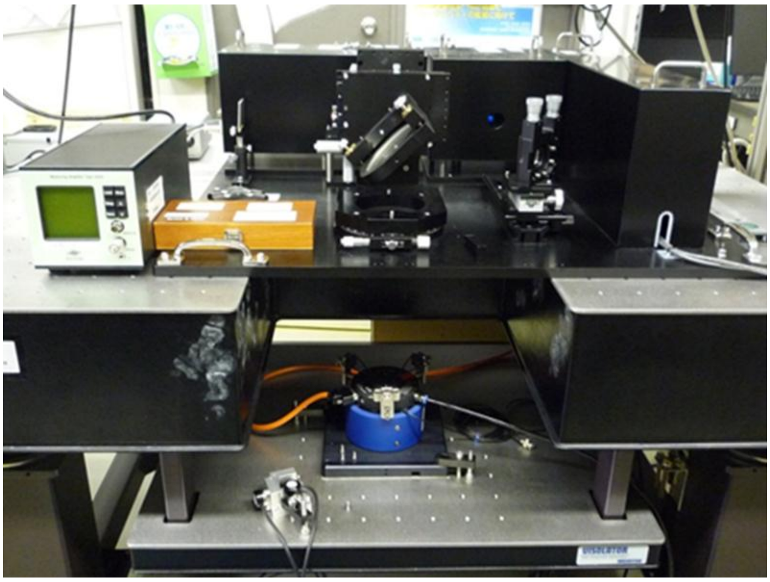

Fig. V4 System 4: 5 kHz to 10 kHz

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

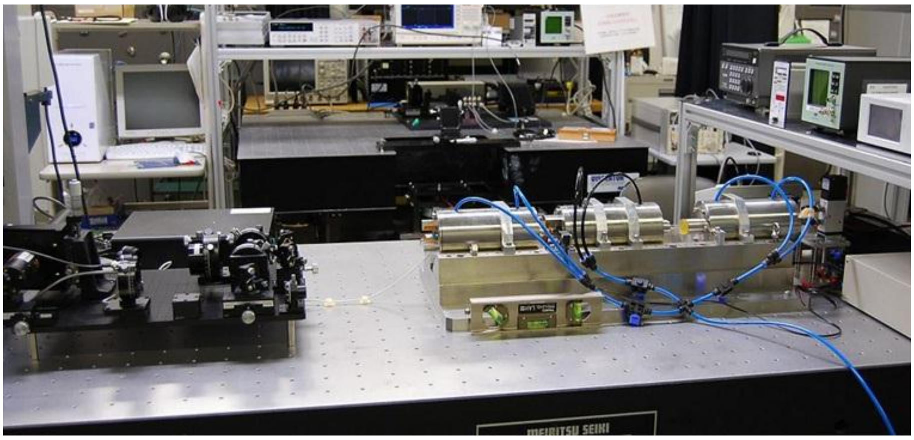

Fig. V5 System 5: Shock acceleration calibration system

System 1 is realized by a combination of 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 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 is in progress together with PTB.

Technical competence in four systems from system 1 to 4 has been confirmed by peer reviews in 2002 and 2007. In next year, peer review will be conducted for technical competence of all systems including shock acceleration facilities.

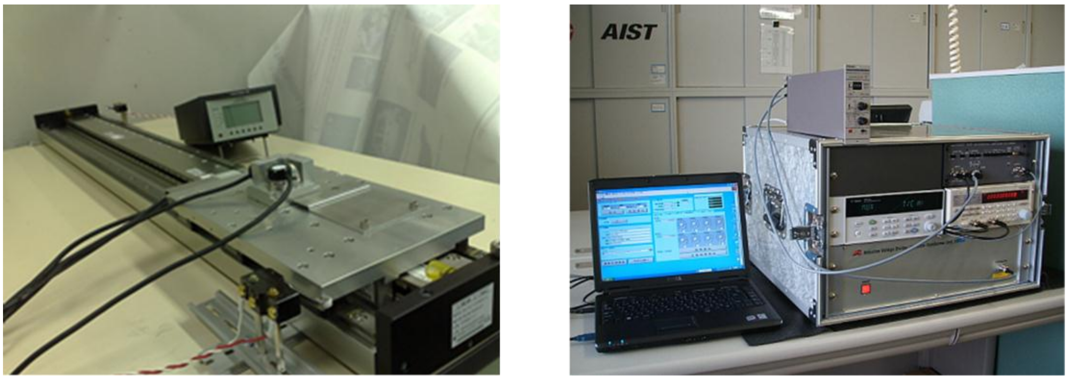

Fig. V6 Transportable calibration equipments

Fig. V7 Digital demodulator for laser vibrometer standard

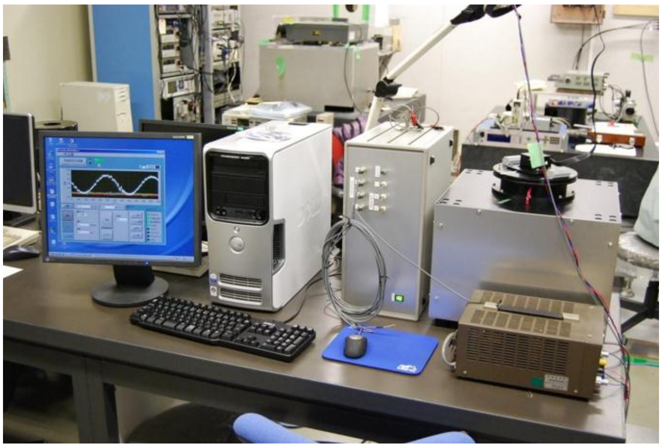

Fig. V8 Angular velocity calibration system under development

Now, NMIJ has been developing transportable calibration system for on-site calibration as shown in **Fig. V6** [17]-[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. V7**[20], [21]. Beside, an angular velocity calibration system from 1 deg/s to 360 deg/s is being developed with the use of a self-calibratable rotary encoder 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, MINT and 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 already completed and the calibration reports from some participants will be submitted soon.

NMIJ completed circulation and reporting for the international comparison, APMP.AUV.V-S1 for low frequency range. In this comparison, system 1 and 2 are used (see Fig.V1 and V2).

We had some damages in vibration calibration systems due to huge earthquake on March 2011, such as oil leak in vibration exciter for low frequency range, position shifting of top table in isolation table, and damage of automatic leveling mechanism in pneumatic vibration isolation table (see **Fig. V9**). But, all our calibration systems were luckily recovered until September 2011. We appreciate NMIs concerned while reporting this recovery.

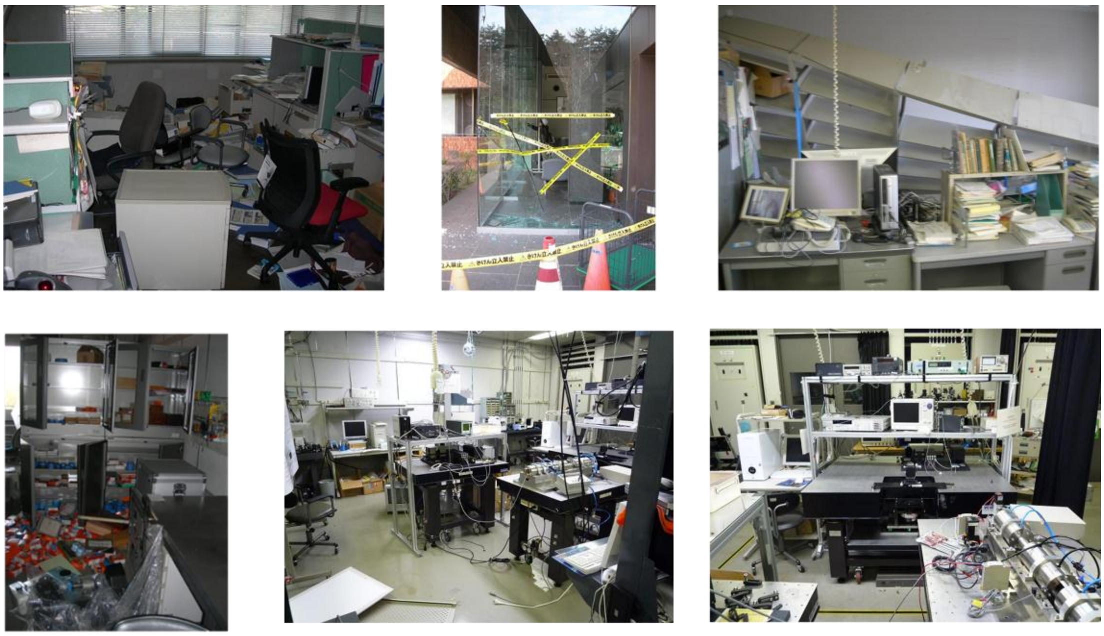

Fig. V9 Damage of NMIJ due to big earthquake on March 2011

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