Measurement traceability of acoustics and vibration instruments in Indonesia

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Abstract. This paper presents the chain of calibration for acoustics and vibration measurement instruments to national standard which must be maintained by NMI (National Metrology Institute). At the present time, NMI in Indonesia is Research Center for Metrology - Indonesian Institute of Sciences (RCM-LIPI). For acoustics measurement instruments are microphone, pistonphone and sound level meter, and for vibration measurement instruments are accelerometer and vibration meter. The implementation of calibration method based on IEC standard is described along with the uncertainty components that contribute to the calibration results. International recognition of calibration and measurement capabilities of RCM-LIPI for acoustics and vibration are shown.

1. Introduction

Acoustics & vibration measurement plays important role for supporting industrial development in many areas. For example, noise emission assessment is usually used by the automotive manufacture and construction. Effective noise control plan could not be applied without proper noise measurement technique and accurate measurement result. In the field of vibration, vibration meter is used for machine health monitoring and product testing. The health of employees related to acoustics & vibration is also protected by government regulation which is issued by Ministry of Manpower of the Republic of Indonesia Number: PER.13/MEN/X/2011, about threshold limits of physical and chemical factors in the workplace is 85dBA and 4m/s² respectively [1]. Measurement technique and instruments plays important rule to obtain reliable measurement result and correct interpretation for the judgment.

Instrument measurement result reliability can be assessed by calibration process where the instrument under test is compared with the reference value and this process is conducted by the calibration laboratory. In order to assure the reliability of reference value used by calibration laboratories, the reference value should be calibrated to standard value as the realization of unit definition and has the highest accuracy. Unit standard in each country is realized and maintained by national metrology institute (NMI). Research Center for Metrology LIPI (RCM-LIPI), previously named KIM-LIPI, is Indonesian NMI which has been registered in International Bureau of Weights and Measures (BIPM) which is the international standard organization for maintaining International System of Units (SI). RCM-LIPI also signs the CIPM-MRA which is show the international equivalence of measurement standards and the certificate among the CIPM member. RCM-LIPI has
been accredited ISO 17025 by KAN, Indonesian accreditation body, as calibration laboratory with the identifier LK 070 IDN [2].

This paper presents the calibration capability provided by acoustics & vibration metrology laboratory of RCM-LIPI. The implementation of traceability from the measurement instrument to the primary standard will be described. Inter-comparison result with other NMIs will also be presented.

2. Calibration Methods

2.1. Acoustics Calibration

Instruments used for acoustics measurement are sound level meter (SLM), acoustics calibrator or pistonphone and microphone the method for calibration of sound level meter is explained in IEC 61672-3:2013, Electroacoustics – Sound Level Meters – Part 3: Periodic Test [3]. This standard gives standard procedure to assess conformity of sound level meter to the standard SLM described in the IEC 61672-1 Electroacoustics – Sound Level Meters – Part 1: Specification [4]. The method use for calibration of SLM is substitution method. Sound generated by speaker is measured by reference microphone at first and then this microphone is substituted by the sound level meter under test. By this process, the sound level meter is traceable to the reference microphone. For the calibration of acoustics calibrator or pistonphone, the method used is insert voltage referring to the IEC 60942:2003, Electro acoustics–Sound Calibrator [5]. In this method, the sound pressure generated by acoustics calibrator is measured by the reference microphone and its voltage output (\(V_l\)) is measured by the voltmeter. This output voltage corresponds to the SPL produce by acoustics calibrator which includes environmental condition effect to the sound pressure like temperature and air pressure. An equivalent electrical signal is then inserted (\(V_{in}\)) directly through the microphone backplate pin bypassing the diaphragm so that the output voltage of microphone equal to \(V_l\). Insert voltage is equal to sound pressure of acoustics calibrator in the ideal condition without environmental effect. The ideal sound pressure generated by acoustics calibrator is then calculated from the reference microphone sensitivity so that the sound pressure produce by acoustics calibrator is traceable to standard unit through the reference microphone sensitivity.

Reference microphone can be calibrated either by secondary and primary method. Secondary method of microphone calibration employs comparison method which is described in IEC 61094-5:2016. In this method, microphone under test and reference microphone are mounted face-to-face with small distance to ensure that both microphones receive the same sound pressure. The sound pressure is generated by pistonphone and output voltage of both unknown microphone and reference microphone are measured. Then, the sensitivity of unknown microphone can be calculated from reference microphone sensitivity [6]. Most precise microphone calibration can be implemented by primary method called reciprocity which is described in IEC 61094-2:2009. In this calibration method, microphone is utilized as sound transmitter and receiver so that ratio of electrical transfer impedance (\(Z_e\)) and acoustics transfer impedance (\(Z_a\)) between the microphones can be measured and calculated [7]. Three microphones (Mic1, Mic2, Mic3) are used in the calibration and configured as transmitter-receiver in three combination (Mic1-Mic3, Mic1-Mic2, Mic2-Mic3) namely configuration A, B, C respectively. Sensitivity of microphones is then obtained by solving these equations:

\[
M_1M_2 = \left(\frac{Z_a}{Z_e}\right)_A \quad M_1M_3 = \left(\frac{Z_e}{Z_a}\right)_B \quad M_2M_3 = \left(\frac{Z_e}{Z_a}\right)_C
\]  

2.2. Vibration Calibration

In the vibration field, accelerometer is employed by vibration meter to measure displacement, velocity and acceleration of the measurement object. Sensitivity of accelerometer can be expressed in charge sensitivity or voltage sensitivity with unit of (pC/m/s²) and (mV/m/s²) respectively. The vibration meter is calibrated using the secondary method named comparison method or back-to-back calibration method. It is called back-to-back because vibration meter’s accelerometer and reference accelerometer
are mounted inline and direct contact on the top vibration exciter. Measurement of displacement, velocity and acceleration by the vibration meter is compared with the reference accelerometer result to obtain correction value for vibration meter under test. By this method, vibration meter is traceable through the reference accelerometer sensitivity. Explanation of calibration technique and uncertainty estimation for this secondary method can be found in the ISO 16063-21:2003 [8].

The primary method for calibration of accelerometer which has the most accurate result is implemented by laser interferometry and briefly described in standard ISO 16063-11:1999. Basis of the method is application of fringe which is constructive and destructive interference of two coherent laser waves. According to the standard, there are 3 methods which can be implemented namely Fringe Counting Method (FCM), Minimum Point Method (MPM) and Sine Approximation Method (SAM) [9]. The differences between the methods are frequency range of calibration and complexity of the method. FCM method determines the sensitivity of accelerometer by measuring fringe frequency with the counter and suitable for calibration of accelerometer in the frequency range of 1 Hz to 800 Hz. In the MPM methods, sensitivity of accelerometer is calculated from the displacement which is measured by using the arguments to the zero crossing of the Bessel function of the first kind and first order. The limitation of this method is the difficulty to detect zero crossing in low frequency therefore frequency range for this method is started from 800 Hz to 10 kHz. Comparing with FCM and MPM, SAM method has the widest calibration frequency range. In the SAM method, quadrature laser interferometer is used and the output which has 2 output signals sampled as \{u_1(t_i)\} and \{u_2(t_i)\}. From these output signals, the series of modulation of phase will be:

\[
\varphi_{mod}(t_i) = \arctan\left(\frac{u_2(t_i)}{u_1(t_i)}\right) + n\pi
\]  

(2)

3. Calibration Uncertainty Components

3.1. Acoustics

The calibration of sound level meter is conducted in the RCM-LIPI’s full anechoic chamber which has the dimension 10 m x 10 m x 10 m, frequency cut-off 63 Hz and background noise about 17 dB. As the reference, microphone type B&K 4180 serial number 1395438 is used for calibration. Uncertainty components of sound level meter calibration are calibration instruments reading resolution, reference microphone sensitivity, digital voltmeter, sound attenuator, acoustics calibrator, drift of reference microphone sensitivity, stability of calibration system and other factor such as the anechoic chamber characteristic and sound level meter placement. These components yield the uncertainty of 0.38 dB within frequency range 63 Hz to 10000 Hz in the sound level meter calibration system. For acoustics calibrator calibration using insert voltage method, uncertainty components contributed by digital voltmeter, reference microphone sensitivity, microphone sensitivity drift, barometer, pressure change, thermometer, temperature change, system stability and rounding error. Total uncertainty for acoustics calibrator calibration is 0.1 dB for the SPL 94 dB, 114 dB, and 124 dB. In the microphone calibration using reciprocity method, calibration of 1 inch microphone and ½ inch use the same system but the uncertainty values for each frequency are different because calibration parameters between 2 microphones are different. Since RCM-LIPI use reciprocity method which is the most accurate method for microphone calibration, many components are considered in the calculation of calibration uncertainty. These components are described as follow:

- Microphone parameter: front depth, front volume, equivalent volume, resonance frequency, loss factor
- Electrical parameter: voltage ratio, capacitance, crosstalk, Polarization voltage, frequency, receiver ground shield, transmitter ground shield, distortion
- Coupler properties: length, diameter, volume, surface area, air leakage
- Ambient Conditions: static pressure, pressure variation, pressure coefficient, temperature coefficient, microphone temperature, temperature variation, relative humidity, microphone, relative humidity
- Physical Correction: radial wave motion, viscosity losses, heat conduction, adding excess value
- Repeatability and rounding error

Minimum uncertainty for microphone sensitivity calibration for ½ inch microphone is 0.06dB and the maximum uncertainty is 0.12dB in the frequency range 20 Hz to 10000 Hz. For 1 inch microphone, the frequency range of calibration is 20 Hz to 25000 Hz with the range of uncertainty from 0.06 dB to 0.17 dB.

3.2. Vibration
The implementation of vibration meter calibration using back to back calibration method is according to IEC 16063-21:2003. Instrument used for calibration are reference accelerometer type B&K 8305 serial 1499872, conditioning amplifier, vibration exciter, amplifier and FFT analyzer. These instruments contribute to calibration uncertainty together with other parameters such as reference accelerometer drift, measurement repeatability, reading resolution of device under test, stability of the system, mounting influence, transducer non-linearity, gravity influence and influence of exciter’s magnetic field. These produce uncertainties ranging from 1.1 % to 1.3 % in the frequency range 20 Hz to 5000 Hz. For the primary calibration of accelerometer, RCM-LIPI implements IEC 16063-11:1999 method 3: sine approximation method. Instruments used for this calibration are Polytech laser Doppler vibrometer, conditioning amplifier and calibration software B&K 3629. In the uncertainty calculation, this primary calibration system considers following components:

- Acceleration amplitude: signal, generator frequency, interferometer signal filtering effect, laser wavelength stability, motion disturbance effect
- Voltage amplitude: voltage measurement error, transverse motion effect
- Conditioning amplifier: capacitance uncertainty, input voltage uncertainty, output voltage uncertainty, conditioning amplifier uncertainty
- Repeatability

Uncertainties obtained by this calibration system are within the range of 0.7 % to 0.9 % in the frequency range of 10 Hz to 5000 Hz.

4. International Comparisons Result

4.1. APMP.AUV.A-K1.1
This registered bilateral comparison conducted between RCM-LIPI with Korea Research Institute of Standard (KRISS) for pressure sensitivity of 1-inch microphone LS1p using reciprocity method. The frequency range of comparison is from 63 Hz to 8000 Hz in octave frequencies and the artefact is microphone B&K 4160 serial number 1792662. The initial calibration was conducted at KRISS and then continued by RCM-LIPI and finally recalibrated by KRISS.

Maximum deviation of microphone sensitivity calibration result between RCM-LIPI and KRISS is 0.05 dB which occurs at frequency 8000 Hz. Compared to the expanded uncertainties, all the deviation still within the range of measurement uncertainties therefore show the equality between RCM-LIPI and KRISS. The final comparison report has been published in the BIPM key comparison database (KCDB) website as the supplementary report [10].
4.2. APMP.AUV.A-K3.1

Bilateral comparison was conducted between RCM-LIPI and KRISS with the artefact of ½ inch LS2p microphone type B&K 4180 serial number 2341431. Calibration frequency range were 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 6300, 8000, 10000, 12500, 16000, 20000 and 25000 Hz. Maximum deviation of sensitivity result is 0.1 dB at frequency 25000 Hz and this value is still in the range of stated measurement uncertainty which shows the degree of equivalence between KRISS and RCM-LIPI. The final comparison report has been published in KCDB websites [11].

4.3. APMP.AUV.A-S1

The subject of this comparison was the measurement of sound pressure level, frequency and total harmonic distortion of multi-frequency sound calibrator. The comparison was joined by 13 countries in Asia which were NMIA Australia, SCL Hongkong, RCM-LIPI Indonesia, CMS/ITRI Taiwan, NML/SIRIM Malaysia, NIM China, KRISS Korea, A*Star Singapore, NMJ Japan, NPLI India, NMISA South Africa, NIS Egypt and NIMT Thailand. The protocol said that calibration method used for comparison follow IEC 60942:2003. The measured sound pressure were 94dB and 114dB with the frequency of measurement were 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 12500 and 16000 Hz. Complete final comparison report which includes sound pressure level, frequency and THD measurement at each frequency can be seen in the comparison result published in the technical supplement of Metrologia journal [12].

4.4. APMP.AUV.V-K1.2

The participants of this comparison were NIM China, RCM-LIPI Indonesia and NPLI India with NIM act as the pilot laboratory. The artefacts of comparison were accelerometer single ended (SE) accelerometer type B&K 8305-001 serial 2519436 and back to back (BB) accelerometer type B&K 8305 serial 2440139. The complex charge sensitivity of both accelerometers should be measured with the method described in IEC 16063-11:1999 for the following frequencies: 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000 Hz. The sensitivity value and the uncertainty of RCM-LIPI and NIM China has shown the equivalence value. The comparison result for each frequency and each BB and SE accelerometer and its uncertainty was published in the KCDB website [13].

4.5. EURAMET.AUV.V-P1

This comparison was conducted between RCM-LIPI and LNE France with the artefact of accelerometer SE type 8305-001 serial 2481861 and BB type B&K 8305 serial 2679379. Sine approximation method as described in the IEC 16063-11:1999 should be used for the calibration of charge sensitivity of accelerometer over frequency range 10 Hz to 10 kHz. The sensitivity value measured by RCM-LIPI was close to the result measured by LNE for SE accelerometer. There is a difference about 0.0005 pC/ms² in low and medium frequency region for BB accelerometer, but these differences are still within the range of uncertainty of both participants which are around 0.001 pC/ms². These results show that accelerometer calibration using laser interferometry method by RCM-LIPI has degree of equivalence with the LNE. The report of this comparison has been approved for the publication in the KCDB website and technical supplementary of Metrologia journal [14].

5. Conclusion

The traceability of acoustics and vibration measurement has been realized by RCM-LIPI as the Indonesian national metrology institute from secondary to primary method. Participation in the international comparison with satisfactory result shows the validity of calibration result and technical capability to perform the calibration according to the standard procedure.
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