Realization of Noise Dosimeter Calibration Based on Percentage of Noise Dose Exposure using Absolute Method

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Abstract. The application of noise dosimeter in an industrial and construction area has shown an increase in the last decade in Indonesia significantly. The benefit of using this acoustical instrument is having a parameter known as a percentage of noise dose exposure that is appropriate for the workers located in a loudness area. Moreover, the industrial necessity related to this instrument calibration quantity tends to increase in recent years. However, the calibration service related to this parameter is not available in Indonesia yet. Therefore, the aim of this work is to realize the calibration of noise dosimeters based on the percentage of noise dose exposure using an absolute method. In this method, it is necessary to apply the insert voltage technique to determine an absolute sound pressure level (SPL), where a whole measurement process is performed in a free field condition. The determined parameter is the percentage of noise dose (D), and time-weighted average (TWA) with SPL of 104 dB and 114 dB. From the result, the deviation value of D between the two devices under test and the reference tends to increase and has maximum values at the frequency of 8000 Hz that the values are 2.2% and 3.7% respectively. Meanwhile for the TWA parameter, the maximum deviation for the first DUT is found at the of 4000 Hz that has the value is 2.4 dB(A), while for the other device is about 4.1 dB(A) at the frequency of 8000 Hz. Besides, these methods are necessary to be implemented for validating the calibration of noise dosimeter using acoustic comparison coupler as a prototype research that still under development.

Keywords: Noise Dosimeter, Percentage of Noise Dose Exposure, Absolute Method, Sound Pressure Level

1. Introduction

Noise dosimeter has an important role to monitor an auditory effects of noise pollution [1]. This instrument has a capability to measure a variance of sound pressure level (SPL) as well as a sound level meter [2]. Moreover, the beneficial of this device is having a main function that is not found in the other acoustic devices generally, where it is capable to calculate a percentage of noise dose exposure parameter directly. By means of this quantity, it makes the convenience for the workers to manage their needs when they work and or located in a loudness area. In addition, the maximum of permissible noise for the employees in Indonesia is 85 dB(A) at the duration time of 8 hours [3].
As the acoustic instrument by its massive application in many industrial and construction area, it should be ensured that the percentage of noise dose exposure that indicated by this instrument is precision and accurate. To assure the eligibility of this device, it is necessary to be calibrated periodically using the recognized method [4]. In addition to having a purpose to monitor its reliability, the calibration of noise dosimeter is important because it is capable to check and assist its main ability parameter such as an internal noise, used filter, long term stability, and of course, it also maintain a traceability chain of acoustics measurement in Indonesia [5]. However, the calibration service related to this parameter is not realized in Indonesia yet, while the number of the industrial necessity related to this instrument calibration tend to increase in recent years significantly. Hence, this is defiance for National Standardization Agency of Indonesia (BSN) as the National Metrology Institute (NMI) to comply the traceability needs and market requisite by implementing a calibration of noise dosimeter. Therefore, the purpose of this work is to realize the calibration of noise dosimeter based on the percentage of noise dose exposure using an absolute method. In this method, it is necessary to use the insert voltage technique to determine an absolute of sound pressure level values, where a whole measurement process is performed in a free field condition [6]. In addition, this paper also provides the result of calibration of two noise dosimeter based on the grade.

According to some publication in the acoustics journal and conference, the related research has been implemented using a coupler method. In this method, a Multifunction Acoustic Calibrator as a laboratory instrument is used as a standard, where the microphone of noise dosimeter should be put to this standard where this state is known as a coupler condition. After that, by comparing the value of the determined quantity between these instruments, the correction value is obtained [6]. Generally, this method is simpler than using the absolute method that will be discussed in this paper. However, the determined correction value is bigger relatively, and it has limited nominal SPL instead of other method that has more variety of SPL.

In principle, calibration of noise dosimeter based on percentage of noise dose exposure parameter has a resemblance of its requirements with other acoustical devices calibration, such as the environmental condition, the used method, the standard or reference device, and the calibration apparatus [6]. However, there are several of specific measurand that determined in the dosimeter calibration, and it is consist of a reference duration time of sound pressure level (T), percentage of noise dose (D) as the main measure and in this work, and the optional parameter that represented by time-weighted average (TWA) [7]. The former is the parameter that should be obtained before calibration is performed, and it can be calculated using the equation 1:

\[
T = \frac{8}{2\cdot L - CL/ER}
\]  

(1)

Where, T is a reference of duration time in an hour, L is the generated sound pressure levels by a sound source in dB(A), while CL is a criterion of sound pressure level that its value is 85 dB(A), meanwhile ER is an exchange number rate that refers to NIOSH, where it has value of is 5 dB(A).

Subsequently, the second measurand can be determined after the measurement of sound pressure level (SPL) is measured, and it can be calculated using the equation 2:

\[
D = \left(\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n}\right)
\]

(2)

Where, D is the percentage of noise dose in %, C_n is the duration time of the particular sound pressure level in hour, while T_n is the reference duration time in an hour that determined in the equation (1). After that, time-weighted average (TWA) that is the optional parameter can be calculated using the equation 3:

\[
TWA = 10 \log \left(\frac{D}{100}\right) + 85 \text{ dB(A)}
\]

(3)
Where \( D \) is the percentage of noise exposure dose in \( \% \) that calculated in the equation 2.

2. Method

The method that used to realize the calibration of noise dosimeter is the absolute method using an insert voltage technique that generally has been performed for calibration, testing, and measurement of other acoustical instruments such as a free-field microphone, sound level meter, sound calibrator, and loudspeaker. Furthermore, this method is utilized a full anechoic chamber with the finite volume and installed sound absorber in its surfaces, and moreover, it has a capability to minimize background noise optimally. In addition, when this method is applied, only the sound source and acoustic transducers such as a microphone that is placed inside the chamber, meanwhile for the other apparatus are in its outside. The equipment and facilities used in this calibration work are as shown in Table 1.

**Table 1.** The equipment and facilities

| Equipment/Facilities                     | General Specification                                                                                                                                 |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Function generator (sine generator)     | Fluke 282 Arbitrary Waveform Generator: Double channel, frequency range 0,1 mHz – 16 MHz, resolution 7 digits, frequency accuracy 10 ppm/year          |
| Power amplifier                         | Brüel & Kjær type 2716: Maximum voltage gain 30 dB, range of frequency response 20 Hz - 20 kHz, output impedance 0,03 Ω                           |
| Reference microphone LS2/WS2            | Brüel & Kjær type 4180, Primary standard/working standard of acoustic measurement                                                                    |
| Insert voltage junction unit            | Brüel & Kjær type 0850                                                                                                                                    |
| Measuring amplifier                     | Brüel & Kjær type 2610                                                                                                                                    |
| Pulse analyzer (Sound analyzer)         | Brüel & Kjær type 3650-C: PC with LAN interface, PULSE software, and IDAe-based data acquisition front-end                                              |
| Digital voltmeter                       | Resolution 6 ½ digits                                                                                                                                      |
| Single directional loudspeaker (loudspeaker) |                                                                                                       |
| Full anechoic chamber                   | Dimension 10 m x 10 m x 10 m, rock wool absorber, 0,1 dB deviation due to characterization and positioning of unit under test at 1 meter in front of a sound source. |
| Noise dosimeter test                    | Class/type 1 (DUT-1)                                                                                                                                        |
| Noise dosimeter test                    | class/type 2 (DUT-2)                                                                                                                                         |

In this work, an experiment was set up using the aforementioned apparatus and the first step is shown in Figure. 1
Figure 1. Determining of an absolute sound pressure level using insert voltage technique

From this figure, a reference microphone was placed inside the full anechoic chamber and was connected to an insert voltage junction, a measuring amplifier, and a digital voltmeter that positioned in a control room. The voltage junction device was switched to calibration mode (cal). After that, a sine generator was plugged into an AC input voltage slot of the analyzer and the measuring amplifier. Then, the generator was adjusted at the frequency of 125 Hz. Subsequently, the environment parameters are necessary to be monitored inside the anechoic chamber, and recorded to obtain the ambient sensitivity value at the SPL of 104 dB using the equation 4.

\[ M_a = M_c + (t_M - t_R) \cdot t_c + (p_M - p_R) \cdot p_c + \Delta_{ff} \]  

(4)

Where, \( M_a \) is the sensitivity of microphone in an ambient conditions (in dB), and \( M_c \) is the sensitivity of microphone that is found in the latest of calibration certificate (in dB). Whilst, \( t_M, t_R \) and \( t_c \) are represented as the measured room temperature, the reference temperature, and the temperature coefficient respectively in °C. Afterward, \( p_M \) is the measured ambient pressure, \( p_R \) is the reference pressure, and \( p_c \) is the pressure coefficient where these parameters is obtained in kPa unit. In addition, the correction values between the pressure and free field condition (\( \Delta_{ff} \)) are necessary to be added in the equation 4, where the value is the function of frequency and can be found in the result of the determination of the difference between free-field and pressure sensitivity levels of half-inch laboratory standard microphone [8].

After determining the ambient sensitivity of the microphone in equation 4, the next can be applied by calculating the output insert voltage (\( V_o \)) as a reference value of this frequency using the equation as follow:

\[ V_o = 10^{\frac{M_a}{20}} \]

(5)

After that, the next step is providing SPL through the sound source in a free-field condition inside an anechoic chamber. In addition, this SPL is corrected to weighting factor-A that the correction value and the actual SPL is shown in table 2, and conform to IEC 61672-1 [9].
Table 2. The corrected sound pressure level

| Frequency (Hz) | Weighting factor-A | Sound pressure level |
|---------------|--------------------|---------------------|
|               |                    | 104 dB-A            | 114 dB-A            |
| 125           | -16.1              | 87.9                | 97.9                |
| 250           | -8.6               | 95.4                | 105.4               |
| 500           | -3.2               | 100.8               | 110.8               |
| 1000          | 0.0                | 104.0               | 114.0               |
| 2000          | 1.2                | 105.2               | 115.2               |
| 4000          | 1.0                | 105.0               | 115.0               |
| 8000          | -1.1               | 102.9               | 112.9               |

By generating the signal through the generator and adjusting its level, the value of sound analyzer was set so to make the display indicated the same value as the reference value, and the voltage output that was read by the voltmeter was recorded after switching the insert junction to insert mode (insert).

The second step of this experiment is shown in figure 2. The reference microphone was installed at the distance of 1 meter from the loudspeaker that was connected to the power amplifier and the sine generator. After that, by switching the insert voltage junction to measuring mode (meas) and adjusting an input level of the generator, the digital voltmeter was arranged so to make the display indicated the same value as the previous step.

Figure 2. Providing of reference SPL through the sound source in a free-field condition

Subsequently, the acoustic signal was generated by the calibration system at the duration time of 24 minutes, and, therefore, the result was indicated to the display of digital voltmeter. Moreover, by inputting this result to the equation 2 and 3, the percentage of noise dose and TWA is obtained.
Finally, by replacing the reference microphone with the noise dosimeter test (DUT) at the same position inside the full anechoic chamber, and generating the same level of acoustic signal through the calibration system that is shown in figure 3, the percentage of noise dose is indicated by this instruments directly. Subsequently, the same step also is performed for SPL of 114 dB at the duration time of 6 minutes. For other of the aforementioned frequencies, all the above same steps also applied.

3. Result and Discussion

The result of measurement of the ambient environmental parameters in this work are shown in Table 3

| F (Hz) | Ref. Mic RH (˚C) | Ref. Mic p (%RH) | Ref. Mic p (kPa) | DUT - 1 RH (˚C) | DUT - 1 p (%RH) | DUT - 1 p (kPa) | DUT - 2 RH (˚C) | DUT - 2 p (%RH) | DUT - 2 p (kPa) |
|-------|------------------|------------------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 125   | 23               | 47               | 100.1            | 24              | 47              | 100.1           | 24              | 48              | 100.2           |
| 250   | 24               | 48               | 100.2            | 24              | 49              | 100.2           | 24              | 49              | 100.2           |
| 500   | 24               | 49               | 100.1            | 24              | 49              | 100.1           | 24              | 49              | 100.2           |
| 1000  | 24               | 49               | 100.1            | 24              | 49              | 100.1           | 24              | 49              | 100.2           |
| 2000  | 24               | 49               | 100.2            | 24              | 49              | 100.2           | 24              | 49              | 100.2           |
| 4000  | 24               | 50               | 100.2            | 24              | 50              | 100.2           | 24              | 50              | 100.2           |
| 8000  | 24               | 50               | 100.2            | 25              | 50              | 100.2           | 25              | 51              | 100.2           |

From this table, it is explained that the alteration of the environmental conditions during the experiment is not significant, where these parameters, therefore, are still in the range of calibration requirements. The measured room temperature at the frequencies of 125 Hz and 8000 Hz shift slightly that its value is about 23 °C and 25 °C respectively during the SPL measurement using the reference microphone, and after that, it increases about 1 °C when the measurement using the two noise dosimeters is performed. Furthermore, the air pressure also go up is about 0.1 kPa at the frequency of 125 Hz and 1000 Hz. Meanwhile for the relative humidity, increasing of this parameter has a little leverage.

By using the absolute method, it has beneficial such as its capability to produce a real value of SPL and minimizing background noise from outside the chamber optimally. However, this method cannot
be applied at the same time when generating the SPL value between the reference and the DUT. Hence, the alteration of the environmental conditions has a high probability to be achieved during implementing this method. Consequently, it can affect to the determination of the ambient sensitivity value for the aforecited frequencies. It can be seen in table 3 that the difference of the recorded environmental condition is found beyond these frequencies. However, the obtained deviations are slight relatively and still in the required range. Therefore, it is acceptable to be processed in the next step.

Next, the results of calibration of noise dosimeter for the percentage of noise dose and time-weighted average (TWA) is shown in table 4.

| Frequency (Hz) | Percentage of noise dose (%) | Time-weighted average (dB(A)) |
|---------------|-------------------------------|-------------------------------|
|               | Ref. mic | DUT - 1 | DUT - 2 | Ref. mic | DUT - 1 | DUT - 2 |
| 125           | 7.549    | 7.8     | 7.9     | 73.779   | 73.9    | 74.0    |
| 250           | 21.352   | 21.6    | 21.7    | 78.294   | 78.3    | 78.4    |
| 500           | 45.138   | 45.3    | 45.7    | 81.545   | 81.6    | 81.6    |
| 1000          | 70.340   | 70.6    | 70.6    | 83.472   | 83.5    | 83.5    |
| 2000          | 83.072   | 83.2    | 83.4    | 84.195   | 84.2    | 84.2    |
| 4000          | 80.800   | 82.3    | 82.6    | 84.074   | 86.5    | 86.5    |
| 8000          | 60.392   | 62.6    | 64.1    | 82.810   | 84.9    | 86.9    |

From this table, it is indicated that the maximum of noise dose percentage is found at the frequency of 2000 Hz that the value of the reference is 83.072%, meanwhile for the devices under test are 83.2% and 83.4% respectively. Hereafter, the frequency of 125 Hz, certainly, has the minimum value of noise dose percentage due to the correction of the weighting factor, that has values of these three devices are 7.549%, 7.8%, and 7.9% successively. Furthermore, the highest TWA values also is found the corresponding frequencies, where it has the values about 84.195 dB(A) for the reference calculation, and about 84.2 dB(A) for the two device under tests. Meanwhile for the lowest value, it is found at the same frequency to the previous parameter for all instruments, that has values about 73.779 dB(A), 73.9 dB(A), and 74.0 dB(A) respectively.

Hereinafter, the deviation values of the reference and DUT in this work are shown in figure 4.
From this figure, the deviation values between standard and DUT has a similarity of its curve trend that is shown from the frequency of 125 Hz to 250 Hz. After that, the deviation of reference and DUT-1 decrease at the frequency of 500 Hz that its value is 0.2% and go up slightly to 0.3% at the frequency of 1000 Hz. In contrast of the previous curve, the next curve represented by the deviation of reference and DUT-2 increase about 0.3% at the frequency of 500 Hz, and go down to 0.3% at the frequency of 1000 Hz. Afterward, both of curves have a tendency to raise up to maximum values at the frequency of 8000 Hz that the values are 2.2% and 3.7% respectively.

Calibration for time-weighted average parameter also is carried out additionally, where the result is represented by curve of the deviation that is shown in figure 5.

![Figure 5. Curve of time weighted average deviation between the reference and DUT](image)

From this figure, the deviation values of between standard and DUT has a tend to decrease slightly from the frequency of 125 Hz to 2000 Hz of the both of curves. After that, the deviation of reference and DUT-1 increase from the corresponding frequency to 4000 Hz that has a deviation value is 2.4 dB(A). Afterwards, the value is decrease to dB(A) at the last frequency. Otherwise, the other curve has a tendency to go up from the frequency of 2000 Hz to the latter thas a maximum deviation is about 4.1 dB(A).

Generally, these DUT has a similar feature and usability in acoustics measurement. However, class-1 of noise dosimeter has a better correction value, especially at the high frequencies. It can be seen that its correction tends to be smoother than class-2 of noise dosimeter at the frequencies of 125 Hz to 4000 Hz, and for the two parameters significantly. However, it is reasonable because class-2 of this instrument has been designed for a purpose to be used for the general application instead of class-1 of this noise meter that used for more complex conditions. According to the International Standard, the class-1 has a narrow range of its maximum acceptance limit for the main parameter, while the class-2 tends to has a wider maximum acceptance limit for the same parameter. Moreover, their long term stability is equal because these devices are manufactured for a long duration time.

4. Conclusion

From the result of the percentage of noise dose calibration, the deviation value of the two devices under test to the reference has a tendency to increase to maximum values at the frequency of 8000 Hz that the values are 2.2% and 3.7% respectively. Meanwhile for the time weighted average parameter, the maximum deviation for the first DUT is found at 4000 Hz that has the value is 2.4 dBA. While for the other device calibration, it has a maximum deviation value is about 4.1 dBA at frequency of 8000
Hz. In addition, the results of class-1 of noise dosimeter calibration tend to have a smaller deviation, exclude at the frequency of 1000 Hz, where it has a same value of both of instruments calibration in the percentage of noise dose parameter.

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