REALIZATION OF TOTAL HARMONIC DISTORTION MEASUREMENT OF ACOUSTIC SOURCE SIGNAL SYSTEM FOR FREQUENCY OF 125 HZ AND 1000 HZ

Realisasi Pengukuran Distorsi Harmonik Total Pada Sistem Sumber Sinyal Akustik Untuk Frekuensi 125 Hz dan 1000 Hz

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Abstract

The measurement of total harmonic distortion (THD) of an acoustic source signal system has carried out in Laboratory Acoustics and Vibration, Sub-directorate of National Measurement Standards for Acoustics and Vibration - BSN. The aim of this research is, therefore, to measure and analize the THD values that produced by the system that consists of a signal generator, a power amplifier, and a passive loudspeaker with fundamental frequencies of 125 Hz and 1000 Hz. This measurement should be implemented because it has never been performed in this laboratory. Moreover, this system always be used for either calibration or measurement of acoustical instruments such as sound level meter and noise dosimeter. The method used to measure THD is a free field method using a full anechoic chamber with narrow band analysis. Measurand to determine THD is sound pressure level (SPL) with output of loudspeaker are 94 dB, 104 dB, and 114 dB. From result of measurement was found THD value of fundamental frequencies of 125 Hz and 1000 Hz. For the former frequency, the maximum THD was found at SPL of 94 dB where its value was 1,86 %. Meanwhile the later, the maximum value of THD was 1,94 % also at SPL 94 of dB. The results of this measurement can be used into uncertainty budget for either calibration or testing of acoustical instruments, and also support for validation of calibration of noise dosimeter based on percentage of noise exposure dose using acoustic comparison coupler that still under research and development in this year.

Keywords: acoustic source signal system, sound pressure level, total harmonic distortion (THD)

Abstrak

Telah dilakukan pengukuran distorsi harmonik total (THD) pada sistem sumber sinyal akustik di Laboratorium Akustik dan Vibrasi, Subdirektorat SNSU Akustik dan Vibrasi. Penelitian ini bertujuan untuk mengukur dan menganalisis nilai THD yang dihasilkan dari sIstem sumber sinyal akustik yang terdiri dari pembangkit sinyal, penguat sinyal, dan loudspeaker pasif pada frekuensi fundamental 125 Hz dan 1000 Hz. Pengukuran ini perlu diimplementasikan karena belum pernah dilakukan sebelumnya. Lebih jauh lagi, sistem tersebut selalu digunakan untuk kalibrasi dan pengukuran instrumen akustik seperti sound level meter dan noise dosimeter. Metode yang digunakan untuk mengukur THD adalah metode free field menggunakan ruang anti gema sempurna dengan narrow band analysis. Besaran ukur untuk menentukan THD adalah tingkat tekanan suara (SPL) dengan keluaran loudspeaker sebesar 94 dB, 104 dB, dan 114 dB. Dari hasil pengukuran, ditemukan nilai THD untuk frekuensi fundamental 125 Hz dan 1000 Hz. Untuk frekeunsi 125 Hz, Nilai THD maksimum yang diperoleh pada SPL 94 dB adalah sebesar 1,86 %. Sedangkan pada frekeunsi fundamental 1000 Hz, nilai THD maksimum sebesar 1,94 % juga pada SPL 94 dB. Hasil dari pengukuran ini dapat digunakan sebagai salah satu sumber ketidakpastian untuk kalibrasi dan pengukuran instrumen dan peralatan akustik di dalam ruang anti gema sempurna, dan mendukung kegiatan validasi untuk kalibrasi noise dosimeter berdasarkan dosis paparan kebisingan menggunakan acoustic comparison coupler yang masih dalam tahap penelitian dan pengembangan pada tahun ini.

Kata kunci: *acoustic source signal system, tingkat tekanan suara, total harmonic distortion (THD)*

1. INTRODUCTION

Deputy of National Measurement Standard BSN (Kedeputian SNSU-BSN), formerly was Research Center for Metrology LIPI (RCM-LIPI) has an acoustic source signal system that consists of a signal generator, a power amplifier, and a passive single directional loudspeaker. It is always used for calibrating and testing the acoustical instruments such as sound level meters, and noise dosimeters. The acoustic signal produced by this system will be distorted due to the harmonics, inhomogeneity of medium, self generated noise of the

instrument, and others (Jaisiva, Neelan and Ilansezhian, 2016). This paper focuses only for the harmonics measurement because it has never been performed in the laboratory. Moreover, it probably can cause the error of reading in an unit under test (UUT) during calibration or testing (Corporation, 2015). Therefore, Research Group for Acoustics and Vibration, Center for Research and Human Resource Development BSN (Pusrisbang SDM - BSN), is necessary to measure and analyze its value. After that, it should be added as a correction of reading of UUT and also will be considered to be used to uncertainty budget for calibration result. However, if the value is smaller or still in limit of acceptance test (4%) (IEC 60942 2017), it may be neglected.

The harmonic distortion is usually expressed as a total harmonic distortion (THD) (Kalibrasi et al., 2014). Measurement of THD can be conducted using a frequency analyzer. To reduce a background noise and sound reflection, it is necessary to use a full anechoic chamber as a measurement medium with narrow band analysis (Ginter and Margolis, 2013). According to IEC 61672-3, fundamental frequencies of 125 Hz and 1000 Hz and sound pressure levels of 94 dB, 104 dB, and 114 dB are mandatory to be used for calibration of sound level meter and noise dosimeter (IEC 61672-3 2013).

The purpose of this work is, therefore, to measure and analize THD of the acoustic source signal system using a band pass filter and frequency analyzer at the aforementioned frequencies and sound pressure levels. In addition, the result of this measurement also support for validation process for calibration of noise dosimeter based on percentage of noise exposure dose using comparison coupler method that still under development in this laboratory

2. BASIC THEORY

In the principle, the sound wave that produced by a sound source is a pure sinusoidal wave (Aswal, Singh, Agarwal, Sharma & Sharma, 2016). However, on its propagation and transmission, it can be demodulated non-linearly in the air, so it also contains the harmonic distortion (Masunaga, Ikefuji, Morise, Nakayama and Nishimura, 2012). It is a sinusoidal component of a periodic wave that its frequency is an integer which equals to multiple of a fundamental frequency. When the waves of a fundamental and harmonic frequency combine to form a superposition wave then the distorted wave is created (Corporation, 2015).

The forming of a non-sinusoidal wave due to the harmonic distortion is shown Figure 1.
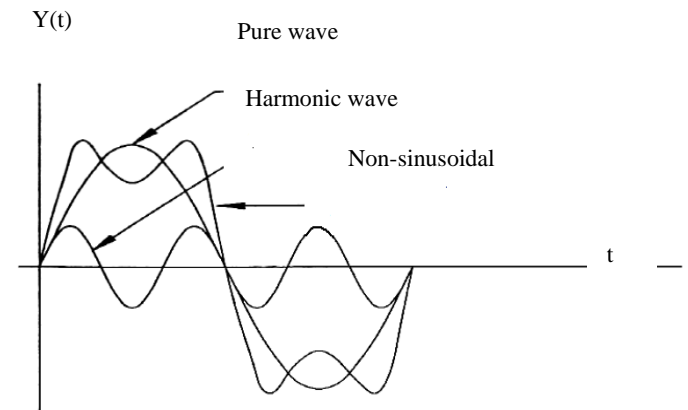

Figure 1 Superposition of the pure wave and the harmonic wave produces a non-sinusoidal wave.

In the acoustic source signal system, the pure wave of specified amplitude and frequency is generated by the signal generator. This wave is then amplified by the power amplifier with a specified gain, and hence its amplitude is bigger than before. Next, this electric signal is converted to the acoustic signal by the passive directional loudspeaker. This signal contains the harmonic component, and will combine with the original wave to form a non-sinusoidal signal. Further, this signal should be measured in a free field condition that basically, it can only be found in the particular area that has an infinite volume where the sound reflections is not detected. However, this conditions can be implemented in anechoic chambers that represent these conditions, where, it has a finite volume and some absorber to minimize the sound reflections (Pollard, Tran & Letowski, 2013). Furthermore, the appropriate method that used to measure this signal is free field method, where, in this method, a sound source is placed inside the center of the chamber (Frederiksen 2013). Then, the receiver is installed at a distance of 1 meter of the source. With using analizer outside the chamber, sound pressure level can be measured.

After that, the signal can be calculated using fourier transform (Alegria, 2016) and the result is shown in equation 1.

$$Y(t) = Y_0 + \sum_{n=1}^{n=\infty} Y_n \sqrt{2} \sin n2\pi ft - \varphi_n \quad [1]$$

Where:

$Y_{(t)}$ = Output signal amplitude

Y_0 = DC amplitude

Y_n = rms value of harmonic component

F = fundamental frequency

φ_n = Phase of angle of harmonic component

T = Time of propagation

The fourier analysis can be used to analyze sound pressure level (SPL) that represents as amplitude and frequency of the distorted signal (Meisami-asl, Sharifi, Mobli, Eyvani & Alimardani, 2013). Representation of the fourier transform of the harmonic signals is shown in Figure 2.
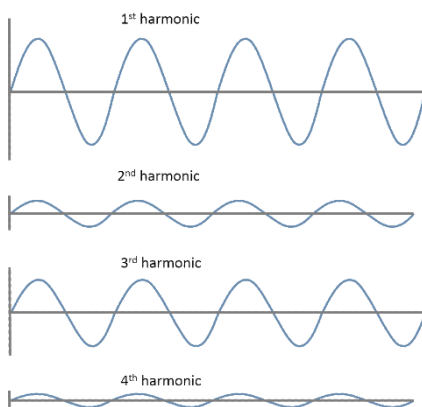

Figure 2 Representation of the fourier transform of the harmonic signals.

Figure 2 shows the result measured with a fundamental frequency of 1 kHz at specified amplitude. The harmonic distortions occur at 2 kHz (1st harmonic), 3 kHz (2nd harmonic), 4 kHz (3rd harmonic), and 5 (4th harmonic) which are the integral multiplication frequency of an input sine wave (Huszty, Yokoyama and Sakamoto, 2010). In measurement, the harmonic distortion is usually expressed as THD that is defined as the ratio of the sum of the output signal of all harmonic components to the output signal of the fundamental frequency (Associated Power Technologies, 2011) and shown in equation 2.

$$THD = \sqrt{\frac{\sum_{n=2}^{n=\infty} M_n^2}{M_1}} \qquad [2]$$

Where:

THD = Total harmonic distortion (%)

M_n = The rms value of current or voltage on harmonic

M_1 = The rms value of current or voltage on fundamental frequency

3. METHODS

There are some methods to measure THD of an acoustic source signal system, such as electrical test and free field methods (Ginter and Margolis, 2013). The former can be applied using time selective response technique without a loudspeaker, while the later can be performed with it. In this work, the second method was chosen to measure THD with narrow band analysis, because the loudspeaker as a part of acoustic source signal systems always be used for calibration and testing of acoustical instruments such as sound level meters and noise dosimeters in BSN. In this method, the loudspeaker and the microphoneis installed in the center of the full anechoic chamber. To determine the THD value, it is necessary to use a band pass filter and a frequency analyzer.

The equipment used in measurement of THD are as follow:

1. The signal generator
Fluke 282 Arbitrary Waveform Generator:
Double channel, frequency range 0,1 mHz – 16 MHz, resolution 7 digits, frequency accuracy 10 ppm/year, output level 25 mV to 10 V p-p into 50 Ω

2. Decade selector/attenuator
GDS EL 100:
Resolution 4 digits, input impedance 600 Ω

3. Power amplifier
Brüel & Kjær type 2716:
Maximum voltage gain 30 dB, frequency response 20 Hz - 20 kHz, output impedance 0,03 Ω

4. Passive directional loudspeaker
Frequency range 31.5 Hz – 10 kHz

5. Digital voltmeter
Fluke 214 7 ½ Digits

6. Multi-frequency sound calibrator
Brüel & Kjær type 4231:
Class LS sound calibrator conform to IEC 60694, SPL 94, 104 and 114 dB, Multi Frequency

7. Standard microphone LS2
Brüel & Kjær type 4180
Primary standard of acoustic measurement

8. Measuring amplifier
Brüel & Kjær type 4231

9. Band pass filter
Brüel & Kjær type 1621

10. Pulse analyzer
Brüel & Kjær type 3650-C
PC with LAN interface, PULSE software, and IDAe-based data acquisition front-end hardware

11. 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.

In this work, an experiment was set up using the aforementioned equipment and the first step is shown in Figure 3. A standard microphone LS2 was placed inside the full anechoic chamber and was connected to a measuring amplifier and a digital voltmeter inside a control room. Next, this microphone was putted off to a coupler of the multi frequency sound calibrator. By selecting frequency of 125 Hz and sound pressure levels at 94 dB, 104 dB, and 114 dB of this sound calibrator, the signal is generated, and thereafter is detected by the microphone. The value of signal is indicated by the digital voltmeter in volt. Further, it is taken as a reference voltage to measure the THD for fundamental frequency of 125 Hz.
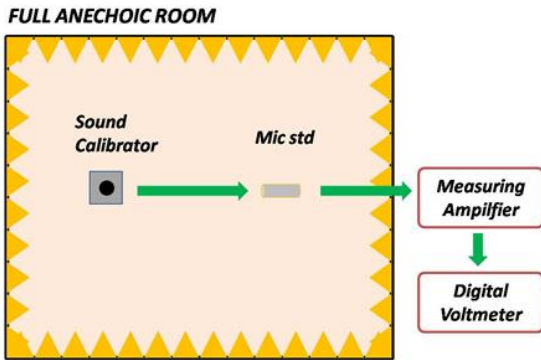

Figure 3 System of equipment to determine a reference voltage.

The second step in the experiment is shown in Figure 4. The standard microphone was installed at the distance of 1 meter from the loudspeaker. Then by configuring the attenuator at normal condition and the power amplifier gain at 5 dB, they are arranged as that shown in Figure 4.
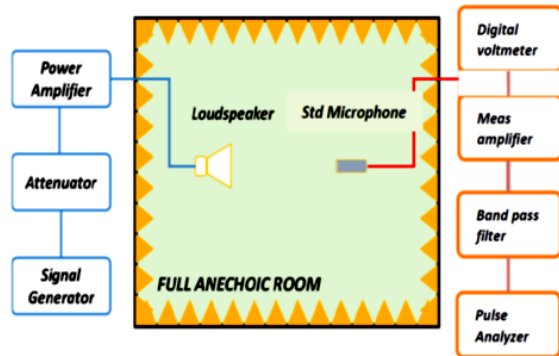

Figure 4 System of equipment of THD measurement.

Thirdly, frequency of 125 Hz was selected by configuring the signal generator menu. After that, by adjusting digits of the attenuator, the digital voltmeter was arranged so to make the display indicated the same value as the reference voltage for sound pressure level of 94 dB, 104 dB, and 114 dB.

Subsequently, the measuring amplifier is connected to the bandpass filter. In order to avoid bypass signal, it is necessary to be configured this filter device by selecting filter bandwidth is 3 % and specified frequency range is 200 Hz – 20 kHz.

Finally, by controlling frequency tunning of the filter, and then selecting window (flat-top) of the pulse analyzer, the harmonic distortion can be monitored and analyzed directly through this analyzer and displayed in the personal computer. For fundamental frequency of 1000 Hz, all the above same steps also applied.

4. RESULT AND DISCUSSION

The result of THD measurement for fundamental frequency of 125 Hz and 1000 Hz at SPL 94 dB are shown in Figure 5 and Figure 6.
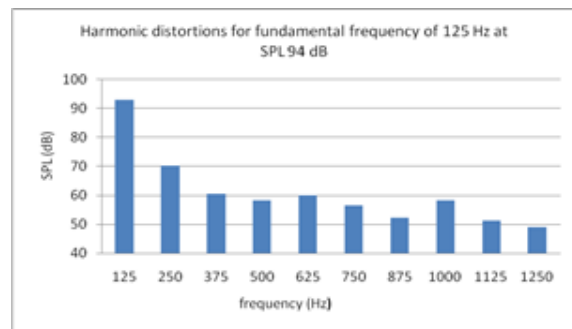

Figure 5 Harmonic distortions of fundamental frequency of 125 Hz at SPL of 94 dB.

From figure 5, at fundamental frequency of 125 Hz it is shown that at the 1st harmonic the SPL is 70,3 dB and tends to decrease until about 58,2 dB at the 3rd harmonic. The SPL values then go up at 625 Hz that represents the 4th harmonic about 60,1 dB and go down about 52,3 dB to the 6th harmonic. Then, the SPL values increase about 58,2 dB at the 7th harmonic and tends to decrease to a minimum value of about 49,1 dB at the last harmonic (1250 Hz).
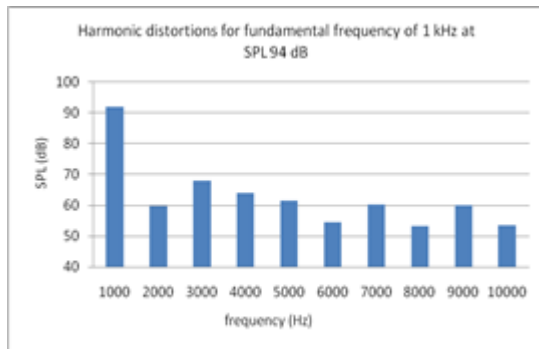
Figure 6 Harmonic distortions of fundamental frequency of 1000 Hz at SPL of 94 dB.

Meanwhile, for fundamental frequency of 1000 Hz is shown in figure 6. It has slightly different of the curve trend with frequency of 125 Hz. At this frequency, it is shown that the SPL values increase from the 1st harmonic that the corresponding SPL is 59,2 dB to the maximum value at the 2nd harmonic that its SPL is 70,3 dB. From this frequency, the SPL values has a tendency to decrease until the 5th harmonic that has SPL value is 56,2 dB. After that, the SPL values go up and go down beyond this frequency where it has a minimum value is 49,1 dB at the last harmonic.
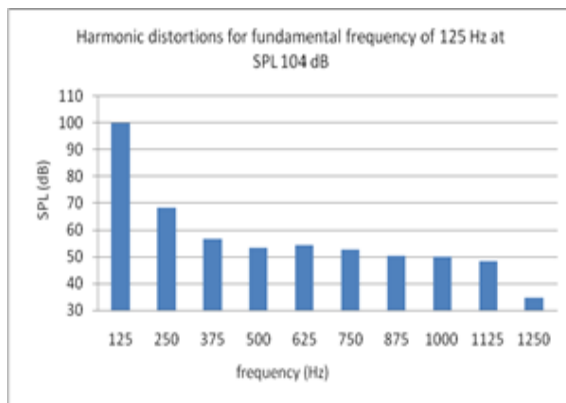

Figure 7 Harmonic distortions of fundamental frequency of 125 Hz at SPL of 104 dB.

In Figure 5 and Figure 6, it is found that at fundamental frequency of 125 Hz, it has a bigger of the SPL values than fundamental frequency of 1000 Hz at the 1st harmonic, the 5th harmonic, and the 7th harmonic. Meanwhile, the other harmonics at fundamental frequency of 1000 Hz has a bigger SPL values. From these SPL values, the THD can later be calculated using the equation (2), where it is obtained that the acoustic source of 125 Hz has the THD is about 1,86 %, whilst for frequency of 1000 Hz is 1,94 %.

The result of THD measurement for SPL 104 dB at fundamental frequency of 125 Hz and 1000 Hz are shown in Figure 7 and Figure 8.
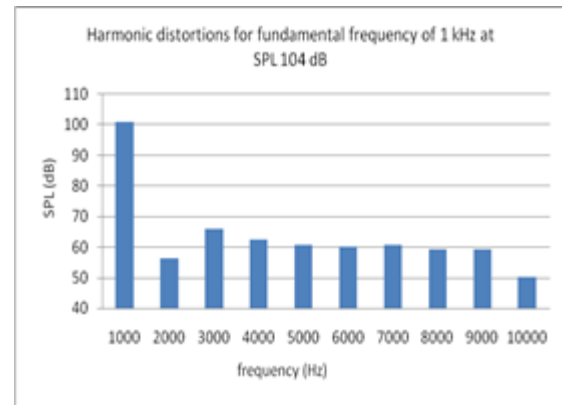

Figure 8 Harmonic distortions of fundamental frequency of 1000 Hz at SPL of 104 dB.

From figure 7, it shown that for fundamental frequency of 125 Hz, the SPL values decrease from the 1st harmonic that the SPL is 68,3 dB until 53,4 dB at the 3rd harmonic. Hereafter, the SPL values go up at the 4th harmonic about 60,1 dB and it has tendency to decrease until the minimum value at the last harmonic that its SPL about 34,7 dB.

Whilst, the different of curve trend is found at fundamental frequency of 1000 Hz that is shown in figure 8. At this frequency, it is shown that the SPL values increase from the 1st harmonic that the corresponding SPL is 56,3 dB to the maximum value is about 70,3 dB at the 2nd harmonic. After that, the SPL values tends to decrease until the minimum value at the last harmonic that its SPL is 50,2 dB.

From both of these frequencies, it is found that at frequency of 125 Hz, it has a bigger of the SPL value only at the 1st harmonic. Furthermore, the SPL of next harmonics has the bigger value at frequency of 1000 Hz. Subsequently, the THD can be calculated using the equation (2), where it is obtained that the acoustic sound of 125 Hz has the THD is about 1,58 %, whilst the THD of sound source of 1000 Hz is about 1,77 %.

The result of THD measurement for fundamental frequency of 125 Hz and 1000 Hz at SPL 114 dB can bee seen in Figure 9 and Figure 10.
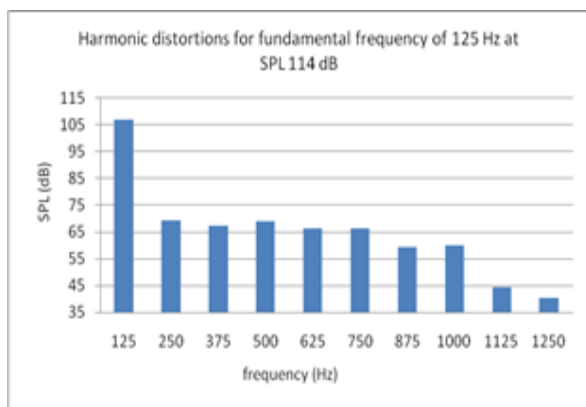
Figure 9 Harmonic distortions of fundamental frequency of 125 Hz at SPL of 114 dB.

From figure 9, it is shown that the 1st harmonic the corresponding SPL is 69,3 dB. After that, the SPL values decrease about 67,5 dB at the 2nd harmonic. After that, The SPL go up and go down until the minimum value at the last harmonic that its SPL is about 40,3 dB.
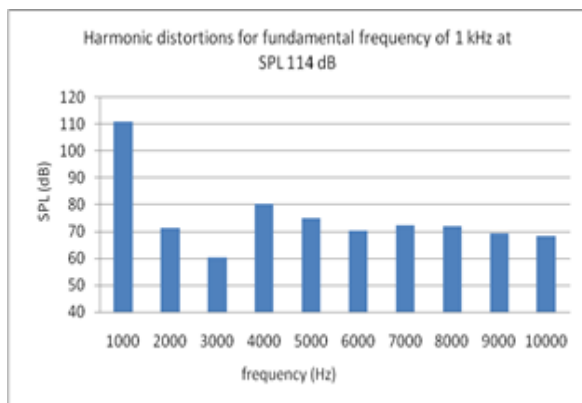

Figure 10 Harmonic distortions of fundamental frequency of 125 Hz at SPL of 114 dB.

Meanwhile, In figure 10 can be seen that at the 1st harmonic, the corresponding SPL is 70,3 dB and tends to decrease to the minimum value about 60,2 dB at the 2nd harmonic. Then the SPL go up at 3rd harmonic with the maximum value about 80,3 dB and go down about 52,3 dB until the 5th harmonic. After that, the SPL values increase about 70,5 dB at the 7th harmonic. Hereafter, the SPL values lean to decrease to about 68,4 dB at the last harmonic.

From these frequencies, it is found that at frequency of 125 Hz, it has a bigger of the SPL value only at the 2nd harmonic. Otherwise, this harmonic order has the minimum value for frequency of 1000 Hz. Furthermore, the SPL of the next harmonics has the bigger value at frequency fundamental of 1000 Hz. Subsequently, the THD can be calculated using the equation (2), where it is obtained that for

frequency of 125 Hz has the THD is 1,71 %, whilst for frequency of 1000 Hz is 1,92 %.

The THD values that are determined from this experiment are in tolerance limit, where its magnitudes are not more than limit of acceptance test that its maximum permissible value is 4%. In order to get a comparation result, in addition, it is recommended to be compared and validated using the calibrated THD meter where the values can be measured through this instrument directly. However, due to the calibration system of THD meter is still under research in BSN, the validation is not performed yet.

5. CONCLUSION

In this work, the measurement of the total harmonic distortion of the acoustic sources signal system at frequency fundamental 125 Hz and 1000 Hz was applied at Deputy of National Measurement Standard BSN (Kedeputian SNSU-BSN) by Research Group for Acoustics and Vibration, Center for Research and Human Resource Development BSN (Pusrisbang SDM - BSN). In fundamental frequency of 125 Hz, the maximum THD was found at SPL of 94 dB where its value is 1,86 %. Meanwhile the later, the maximum value of THD was obtained is 1,94 % also at SPL of 94 dB. In conclusion, eventhough the THD values of the aforementioned frequencies can be added into uncertainty budget on calibration or testing of acoustical instruments, however, it can be neglected because these values are less than the maximum acceptance limit that its value is 4%.

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