

Design and Verification of Acoustic Room for Consumer Product Safety Testing

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Abstract: Sound Producing Toys consists the sound emitting characteristics to attract children's attention, such as emitting music or simulating animal's call. The excess sound pressure level (SPL) could damage the human hearing. The international toy safety standards are established to limit the maximum sound pressure level emitted from the product. The Chief Executive of the Hong Kong SAR established the Task Force on Economic Challenges (TFEC) on October 2008. In early 2009, the TFEC has identified six economic areas where Hong Kong enjoys clear advantages. The Six Industries are (i) testing, inspection and certification (TIC), (ii) medical services, (iii) innovation and technology, (iv) cultural and creative industries, (v) environmental industries, and (vi) educational services. The Open University of Hong Kong is offering the undergraduate degree programmes in testing and certification. For the teaching and research purpose, an acoustic room was built to support the areas of sound pressure level measurement in the Open University of Hong Kong. The acoustic room was primarily designed to serve the sound pressure level measurement of the consumer products, including toys and children's products and gain the Hong Kong Laboratory Accreditation Scheme (HOKLAS) with reference to ISO/IEC 17025. This paper describes the flow of design, consideration of design factors, verification method, applications and limitations of acoustic chamber.

Keywords: Acoustics, Safety, Sound Pressure Level, Toys

1. Introduction

The excess sound pressure level may damage the human hearing capability. The ISO Guide 50: 2014 is the Guidelines for child safety and concludes fourteen different safety hazards. Robert V. Harrison concluded that the high intensity impulsive sound can damage the cochlea and the low level of sound can also induce the metabolic changes in sensory cells. Sound is the sensation of acoustic waves and travel through a medium (e.g. air). Human ear can detect the root-mean square (RMS) value of the pressure fluctuations from 0.00002 Pa to 20 Pa with a frequency range of 20 Hz to 20 kHz. As human ears respond logarithmically to the sound difference, Alexander Graham Bell invented the unit "Bel" to measure the sound hearing. The scale converted the sound pressure level 2-5 Pa to 0 dB, 20 Pa to 120 dB [1 - 7].

Since human ears also have different responses at different frequencies, scientists established both the A weighting and C-weighting to reflect different responses. Researchers have

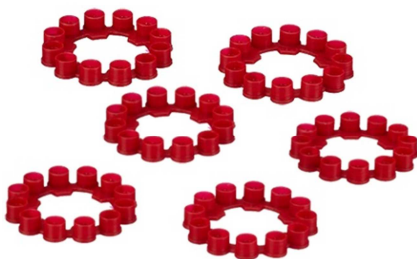
found that operator's hearing would be damaged if they had been worked in the environment with 85 dBA over 8 hours [8, 9]. This limit has been widely adopted in many occupational safety and health standards. On the other hand, the Consumer Product Safety Commission (CPSC) in the United States evaluated the risk of product emitting impulsive noise (i.e. the duration always less than 1 second), such as the percussion caps used in a toy gun, as shown in Figure 2.

The first feeling of baby development is hearing. In fact, it is well known that babies develop hearing ability even before they are born. The baby's ability to respond to sounds lasts for several months before birth and can be fully developed within one month of birth. For the infant toys and nursey products, they were designed to emit the sound in order to attract the babies' attention; the hearing capability may be damaged if the emitted sound pressure level is too high. In order to reduce the risk of hearing damage, the regulatory bodies and standard bodies developed the toys and children's product safety standards to limit the sound pressure level emitted by the products. Table 1 lists the international toys safety standards [10].

Table 1. List of International Toys Safety Standards.

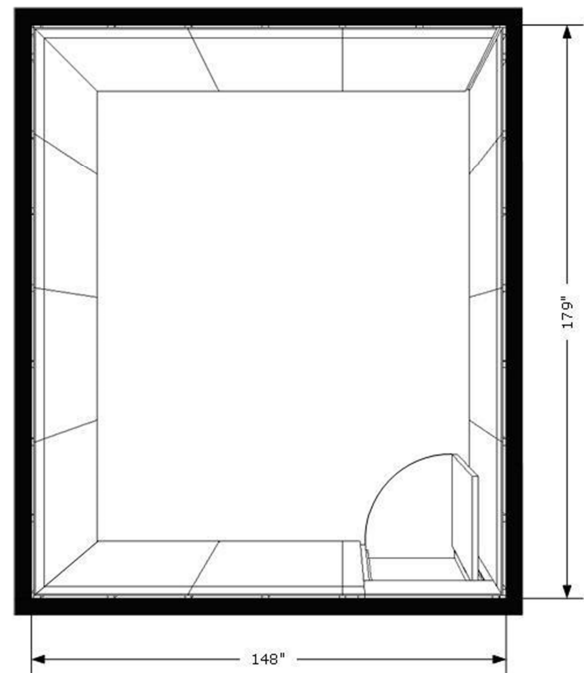
Country	Code of Toys Safety Standard
Argentina, Brazil	NM 300
Australia, New Zealand	AS/NZS ISO 8124
Canada	Canada Consumer Product Safety Act, Health Canada Test Manual
China	GB 6675
European Union	EN 71
India	IS 9873
Jamaica	JS 90
Japan	Japan Toys Safety Standards
Malaysia	MS ISO 8124
Taipei, China	CNS 4797
United States of America	ASTM F963

The European Economic Community (EEC) established the Toy Safety Directive (88/378/EEC) in 1988 and appoint the European Toys safety standards EN71 to be the harmonized standards. The first edition was published in 1988 and the version did not include the acoustic requirement. Then the new version of EN71 Part 1 was published in 1998 and it is the first toy safety standard established the detailed safety requirement and measurement methods to measure the sound pressure level emitted from the toys. Before this standard was published, the Consumer Product Safety Acts of United States only required the impulsive sound pressure level percussion caps (Figure 1) shall be less than 138 db (A). Canada required all toys products shall not emit the sound pressure level over 100 dB; but no detailed sound pressure level measurement method was specified. The European Union announced the new Toy Safety Directive (NTSD) 2009/28/EC in year 2009 and replaced the Toys Safety Directive 88/378/EEC in year 2012. The European Toys Safety Standard, EN71 Part 1 is continued to be one of the harmonized standards of European Commission Directive 2009/48/EC. Started from the 1998 version of the standard, it includes the acoustic requirement of sound-producing toys and described the requirement of sound measurement site, i.e. the background sound pressure level shall be at least 10 decibel (dB) less than the sound pressure level emitted by the toy. The Technical Committee (TC) 52 of European Committee for Standardization (CEN) further reviewed the environmental requirements and published the revision of acoustic parts of EN71-1 on December 16, 2011 [11, 12].

**Figure 1.** Percussion Caps used in a Toy Gun [13].

The Hong Kong government accepted the recommendations from the Task Force on Economic Challenges (TFEC) to develop the 'Testing & Certification'

and other five industries in Hong Kong. The Open University of Hong Kong has launched a series of degree programmes focusing on Testing and Certification from 2011. The four new laboratories were being built in 2012 to support the teaching and research purposes. Figure 2 shows the floor plan of the acoustic room, which is located inside the Physical and Mechanical Testing and Certification Laboratory of the OUHK. The project team designed the acoustic room to meet the European Toys Safety Standard, EN71-1, that specified the environmental requirements of acoustic room for measuring the sound pressure level emitted by the sound-producing toys.

**Figure 2.** Floor Plan of Acoustic Room in the Open University of Hong Kong.

2. Consideration of Factors to design an Acoustic Room

When the project team designed the acoustic room, the team referred to Romon Rusz's suggestion to take in the consideration some of the following requirements: (1) test specimen dimension; (2) acoustic room dimensions; (3) anechoic treatment selection; (4) absorption material design; (5) wedge shape design; (6) room modes consideration; (7) cut-off frequency; (8) transmission loss; (9) vibration isolation; (10) ventilation system requirements; and (11) visual requirements. A dedicated acoustic room is required to carry out the sound pressure level measurement for toy products. Due to the following technical requirements specified in the standards and characteristics of the products, some factors were considered and explained in the following sections [14 - 16].

2.1. Test Specimen Dimension

EN 71-1 established the limit of sound pressure level for

three different categories of toys. The dimensions of four different types of toys were measured and summarized in table 2. The toys with maximum dimension of 1 m (Width) x 1 m (Length) x 1 m (height) can be tested in the acoustic chamber and it can cope most types of toys.

Table 2. Dimensions of Four different types of sound-producing toys.

Types of toy	Length (cm)	Width (cm)	Height (cm)
Hand-held toy (Toy Gun)	27.9	5.6	15.4
Rattles	6.8	17.5	6.6
Squeeze toy	29.1	9.9	5.0
Table-top toy	14.1	5.3	6.3

2.2. Acoustic Room Dimensions

According to the safety standard, the table top toys shall be placed on a standard test table that complied with ISO 7779

(Figure 3). And the pull-along toys (Figure 4) will be also tested; the dimension of test table was extended to 1.5 metres in order to provide enough travelling distance for reaching the travelling speed in 2 meters per second. The distance between the wall and the standard test table shall be at least 1 meter to minimum the effect of sound wave reflection. ISO 3745 also required to consider the dimension ratio of test specimen to the acoustic room. As we defined the maximum dimensions of test specimen is 1 m (Width) x 1 m (Length) x 1 m (height), the volume of test specimen is 1 cubic meter. The minimum dimension and volume of acoustic room is shown in the table 3. The volume of acoustic room is 23.1 cubic meters, the 5% volume of acoustic room is 1.16 cubic meters, greater than the volume of test specimen. We can conclude the internal dimensions of acoustic room met the ISO 3745 requirements [17].

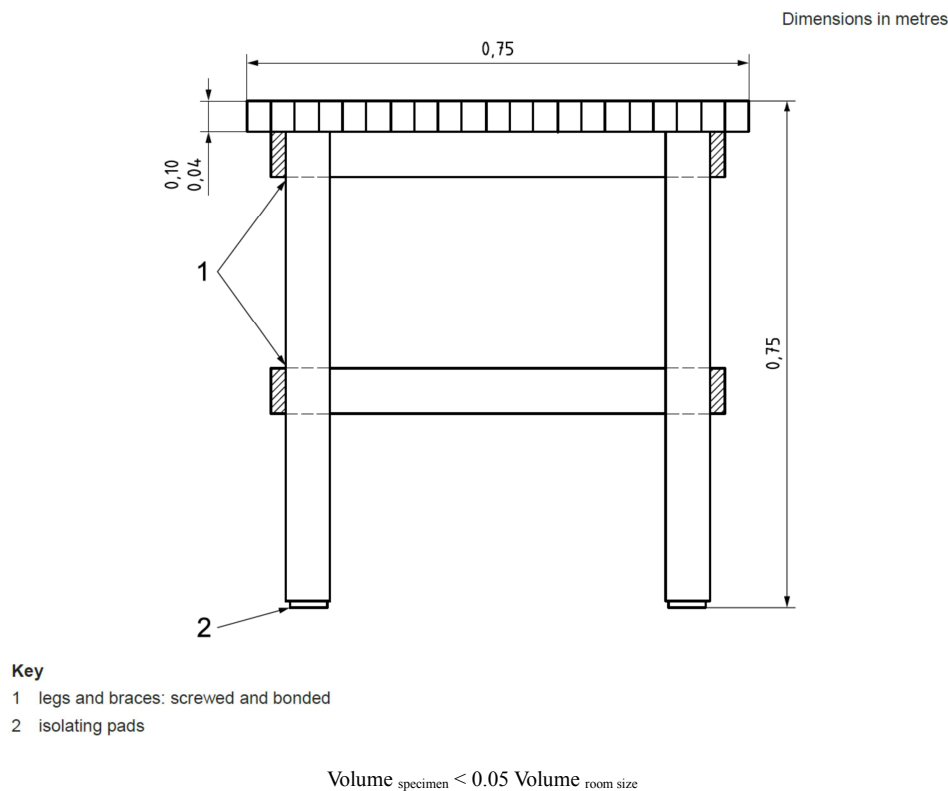


Figure 3. Standard Test Table for Sound Pressure Level Measurement [18].



Figure 4. Pull along toys.

Table 3. Dimensions of Standard Test Table and Acoustic Rooms.

Dimension	Standard Test Table	Room Size
Length (m)	1.5	3.5
Width (m)	1.0	3.0
Height (m)	1.2	2.2
Volume (m ³)	--	23.1

The EN71-1 standard was usually referred when establishing the technical requirements of the acoustic room. It is required to meet the requirements of EN ISO 11201 or EN ISO 11202 by estimating or measuring the equivalent sound absorption area in the test room with reference to EN ISO 3744 or EN ISO 3746. Table 4 shows the basic technical requirement of an acoustic room described in EN ISO 11201 and EN ISO 11202 [12]. The environmental correction factor, K_2 , is to correct the influence of the room noise. The environmental correction factor, K_2 , is determined by the measurement result of the energy average of the time-averaged sound pressure levels over the microphone positions on the measurement surface. The environmental

correction factor, K_2 , is expressed in decibels, dB [19 - 21].

The background sound pressure level shall be at least 15

dB less than the sound pressure level emitted by the testing sample [22].

Table 4. Technical Requirements of acoustic room described in EN ISO 11201 and EN ISO 11202.

Standard	Accuracy Level	Accuracy Grade	Requirement
EN ISO 11201	1	Precision Grade	Meet the EN ISO 3745
EN ISO 11201	2	Engineering Grade	$K_{2A} < 2.0$ dB
EN ISO 11202	2	Engineering Grade	$K_{3A} < 4.0$ dB

3. Selection of Sound Reduction Methods

The acoustic room was designed to carry out the sound pressure measurement emitted by the consumer products (e.g. toys). The two common types of sound absorbers to build the acoustic room are porous absorbers and panel absorbers. Porous absorbers are made of fiber glass and foam that provide the dissipative effect due to friction. It is more effective when its thickness is equal to quarter of the sound frequency. As the background noise composed with different frequencies, the use of porous absorber may not be very effective in removing the background noise level. The second type of sound reduction method is to use panel absorbers (Figure 5). The panel absorbers provide the dissipative effect when the inherent damping happens at bending waves in panel. The performance of panel absorber can be increased by spacing the panel away from its backing surface with the space filled with porous material, particularly for panel resonant frequency [23, 24].

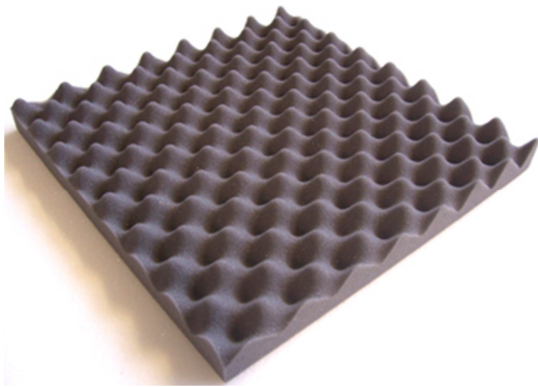


Figure 5. Panel Sound Absorbers.

In order to maximize the sound reduction performance, both reduction methods were applied in the OUHK's acoustic room. The porous absorbers were firstly installed, and covered by a plaster, then a layer of panel absorbers were installed on the outer surface of plastic (Figure 6).

As the plaster board was a kind of brittle material, its impact strength is weak. Therefore sudden impact shall be avoided during sound pressure measurement. For example, a "pass-by" test was mentioned in the toys safety testing standard and applicable to movable toy vehicle. For the panel absorbers, it is made of foam and low tear strength. If torn, the sound absorbing performance will be reduced. Therefore, the infra-structure of acoustic room shall be regularly

checked in order to maintain the performance.



Figure 6. Panel Absorbers was stuck on the surface of plaster board.

4. Performance Verification of Acoustic Room

In order to determine the performance of the acoustic room in the OUHK, the EN ISO 3745: 2012 requirements were used to determine the environmental correction, K_2 . The apparatus used include the standard sound source (Figure 7) and the sound analyzer test system (Figure 8) [25 - 28].



Figure 7. Bruel & Kjaer Sound Source HP 1001.



Figure 8. Bruel & Kjaer Sound sound analyzer test system. 3160-A-042.

As the standard required to place the testing specimen on the acoustically reflecting plane for conducting the emitting

sound pressure level. When we verified the acoustic room, we place the standard sound source in the middle of the measurement site (hemisphere-shaped). When the standard sound source is placed on the reflective plane,

the measurement surface, $S = 2\pi r^2$

The location of microphone positions are marked with numbers 1-10 [22]. The 10 measuring locations were shown in Table 2 and Figure 9. The overall A-weighted sound pressure level was listed in the Table 3. Table is as follows: Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”.

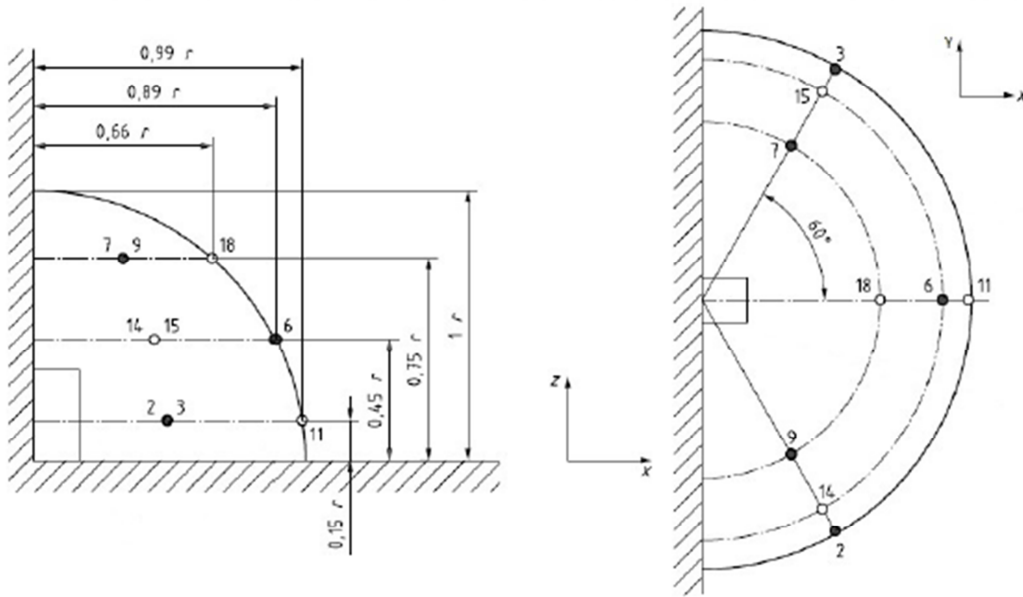


Figure 9. Locations of Sound Pressure Level Measurement.

Based on the measurement results, the environmental correction factor (K_{2A}) is less than 2 dB. In other words, it met the requirements of engineering grade of acoustic room and suitable for the sound pressure level measurement of consumer product safety testing.

Table 6. Measurement Result of different locations in the acoustic room.

Frequency (Hz)	Background Sound Pressure level (dB)	Environmental Correction, K_2 (dB)
100	48.4	2.1
125	31.3	2.9
160	28.4	2.5
200	30.6	3.4
250	27.6	2.8
315	28.1	4.5
400	25.0	4.6
500	25.3	2.0
630	21.4	1.1
800	17.9	1.5
1000	16.1	2.7
1250	12.2	1.1
1600	8.2	0.1
2000	6.4	-0.2
2500	5.7	-0.1

Table 5. Locations of Sound Pressure Level Measurement.

Location	x/r	y/r	z/r
1	-0.99	0.00	0.15
2	0.50	-0.86	0.15
3	0.50	0.86	0.15
4	-0.45	0.77	0.15
5	-0.45	-0.77	0.15
6	0.89	0.00	0.45
7	0.33	0.57	0.75
8	-0.66	0.00	0.75
9	0.33	-0.57	0.75
10	0.00	0.00	1.00

3150	5.8	0.2
4000	6.0	0.5
5000	6.0	0.1
6300	6.2	0.2
8000	6.2	-0.1
10000	6.0	0.1
Overall A-weighted sound pressure level	32.7	1.1

5. Conclusion

This paper reviewed the technical requirements of an acoustic room for measuring sound pressure level emitted by consumer products. The design concepts and selection of materials were discussed and assessed in order to meet the actual use. A verification measurement was done to ensure the acoustic room met the requirements of background noise level and environmental correction factor that were listed in international standards.

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