MECH9235 – Fundamentals of Acoustics

Laboratory 2 Report

An investigation into measuring sound in a semi-reverberant field using the Direct and Comparative Methods.

Chi-Wai Kou
z3414579
23rd of May, 2016

Contents

MECH9325 – Report, Laboratory #1

Chi-Wai Kou (z3414579) *27th of April, 2016*

1. Introduction

The second laboratory session of this course examined the measurement of sound power levels of an electric drill on a hard surface in a semi-reverberant field. Two correction methods were used to adjust for reverberation effects: the direct method and the comparison method. The measurements were done in accordance with the Australian Standard's procedure outlined in the AS 1217.5 document. The results of each of the methods were compared and analysed.

2. Instrumentation

The following equipment was used during the laboratory session:

- ***Brüel & Kjær Type 4231 Sound Level Calibrator*** *(hereby referred to as "Calibrator")*
- ***Brüel & Kjær Type 2250 Sound Level Meter*** *(hereby referred to as "Sound Meter")*
- ***Brüel & Kjær Type 4204 Reference Sound Source***
- ***Makita Electric Drill*** *(hereby referred to as "Drill")*

Hearing protection in the form of memory foam earbuds was also provided.

3. Procedure

1. Initial Setup

a. The equipment was gathered and assembled.
    i. All components requiring power were connected to general power outlets.
b. The sound meter was calibrated.
    i. The external calibrator was used to calibrate the device
        1. The sound meter was switched on.
        2. The calibrator was attached to the receptor end of the sound meter.
        3. The calibrator was activated, producing a 94dB sound at 1,000 Hz.
        4. After the calibrator signalled that the device had finished calibrating, it was removed. At this point, the sound meter was ready for use.
c. The hemispherical measurement configuration was generated, with the coordinates labelled as denoted in Figure 1 and Table 1, below:

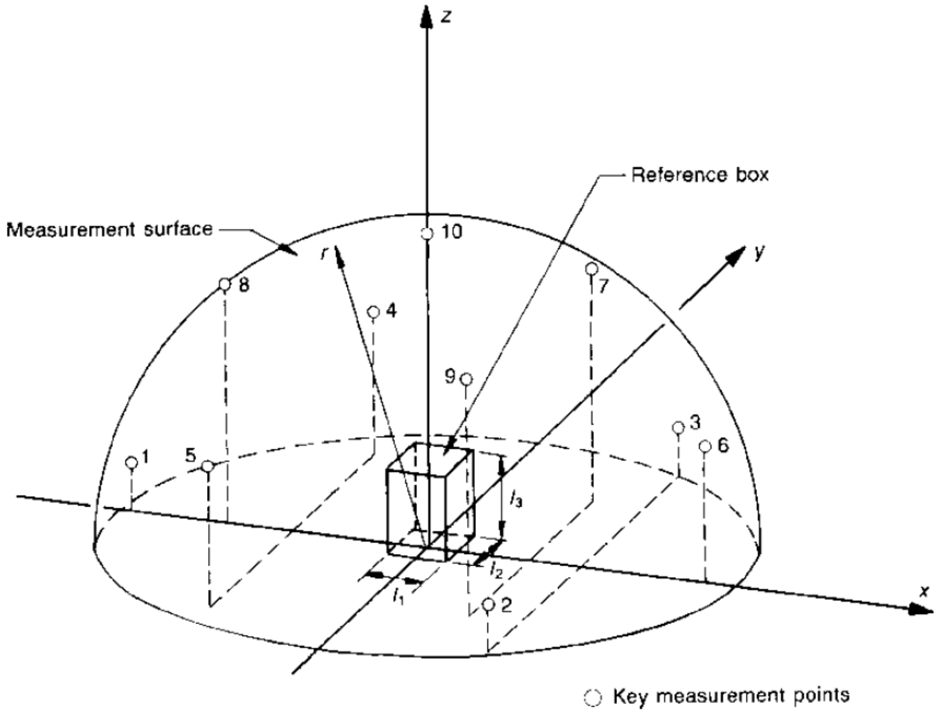

Figure 1 *–The hemispherical measuring configuration*

COORDINATES OF KEY MEASUREMENT POINTS

No	$\frac{x}{r}$	$\frac{y}{r}$	$\frac{z}{r}$
1	-0.99	0	0.15
2	0.50	-0.86	0.15
3	0.50	0.86	0.15
4	-0.45	0.77	0.45
5	-0.45	-0.77	0.45
6	0.89	0	0.45
7	0.33	-0.57	0.75
8	-0.66	0	0.75
9	0.33	0.57	0.75
10	0	-0	1.0

Table 1 *– Coordinates of key measurement points in the hemispherical measuring configuration*

2. Measurement Using the Direct Method

a. The drill was placed in the centre of the hemispherical measuring configuration.
   i. The hemispherical configuration was arranged as with Figure 1, with the coordinates of each reference point is listed in Table 1.
b. The sound meter was set to make measurements with an A-weighting adjustment. Additionally, the sound meter was set to measure specific frequencies.
c. The sound meter was held at arm's length and tilted at a 45° angle upwards (pitch axis), with the lateral line (yaw axis) pointed towards the drill. This gives the most accurate measurements.
d. The drill was turned on.

e. The sound level meter measured the A-weighted sound pressure level of the running drill at the 10 points of measurement in the hemisphere.
    i. Data was recorded for frequencies 125, 250, 500, 1000, 2000, 4000 & 8000Hz.
    ii. The data from the sound meter was tabulated, then recorded in a spreadsheet.

f. When all the measurements were complete, the drill was turned off and removed from the measurement hemisphere.

3. Measurement Using the Comparison Method

a. The B&K 4204 reference sound source was placed in the centre of the hemispherical measuring configuration.
    i. The hemispherical configuration was arranged as per Figure 1 and Table 1.

b. The sound meter was set to make measurements with an A-weighting adjustment. Additionally, the sound meter was set to measure specific frequencies.

c. The sound meter was held at arm's length and tilted at a 45° angle upwards (pitch axis), with the lateral line (yaw axis) pointed towards the drill. This gives the most accurate measurements.

d. The reference sound source was turned on.

e. The sound level meter measured the A-weighted sound pressure level of the running drill at the 10 points of measurement in the hemisphere.
    i. Data was recorded for frequencies 125, 250, 500, 1000, 2000, 4000 & 8000Hz.
    ii. The data from the sound meter was tabulated, then recorded in a spreadsheet.

f. When all the measurements were complete, the sound source was turned off and removed from the measurement hemisphere.

The equipment was replaced after completing all legs of the experiment, and the results saved.

It is noteworthy that, although the procedure undertaken during the laboratory uses an A-weighting during the recording, the results provided in Moodle are given in units of dB, not dB(A), and therefore are not A-weighted. The following results and discussion will use the unweighted results from Moodle.

4. Results & Discussion

Results

The sound pressure levels recorded for the drill for the direct method outlined was recorded and tabulated in Table 2 below. Table 2 shows these measurements across the frequencies in question.

Frequency [Hz]	**1** [dB]	**2** [dB]	**3** [dB]	**4** [dB]	**5** [dB]	**6** [dB]	**7** [dB]	**8** [dB]	**9** [dB]	**10** [dB]
125	55.5	57.8	54.7	54.1	54.8	54.6	53.9	54.0	53.5	52.0
250	53.6	54.6	52.6	52.5	52.0	52.0	51.7	52.3	52.0	52.9
500	53.6	55.4	53.6	52.8	53.8	53.3	54.3	53.4	53.1	53.1
1000	57.2	59.5	59.3	60.5	58.8	57.9	57.3	60.5	60.5	58.8
2000	63.0	63.7	61.5	63.8	61.0	62.1	61.8	62.5	63.2	64.4
4000	63.4	62.1	61.7	67.8	64.4	61.5	61.9	61.4	61.6	60.1
8000	62.6	63.0	62.7	61.8	62.8	62.0	61.0	61.8	60.5	56.0

Table 2 *– Sound pressure level data of the drill across the points of the hemispherical configuration for the specified frequencies*

Similarly, the sound pressure levels recorded across the specified frequencies for the reference sound source for the comparative method was recorded in Table 3 below.

Frequency [Hz]	**1** [dB]	**2** [dB]	**3** [dB]	**4** [dB]	**5** [dB]	**6** [dB]	**7** [dB]	**8** [dB]	**9** [dB]	**10** [dB]
125	75.8	76.1	74.3	75.0	75.0	74.5	72.8	73.3	72.0	68.8
250	76.9	76.7	75.5	75.6	75.2	75.4	73.2	74.2	73.0	72.3
500	77.9	78.1	76.6	76.0	75.6	75.9	74.1	74.5	74.1	76.0
1000	79.9	79.9	77.8	78.9	79.2	77.6	79.6	80.1	79.8	81.6
2000	77.7	72.2	78.8	80.6	80.1	80.2	78.8	79.0	79.0	78.4
4000	77.8	78.0	76.0	77.1	76.9	76.6	75.4	75.3	74.9	72.5
8000	73.2	72.2	71.1	72.2	71.9	71.7	70.2	69.5	69.0	66.0

Table 3 *– Sound pressure level data of the reference sound source across the points of the hemispherical configuration for the specified frequencies*

Since these measurements are not A-weighted, an A-weighting is applied to yield the figures in Tables 5 and Table 6. The A-weightings used are taken from the Unit 5 lecture notes, appended in Table 4:

Frequency [Hz]	**A-Weighting** [dB(A)]
125	-16.1
250	-8.6
500	-3.2
1000	0.0
2000	+1.2
4000	+1.0
8000	-1.1

Table 4 *– A-weightings for frequency bands involved*

Frequency [Hz]	**1** *[dB(A)]*	**2** *[dB(A)]*	**3** *[dB(A)]*	**4** *[dB(A)]*	**5** *[dB(A)]*	**6** *[dB(A)]*	**7** *[dB(A)]*	**8** *[dB(A)]*	**9** *[dB(A)]*	**10** *[dB(A)]*
125	39.4	41.7	38.6	38.0	38.7	38.5	37.8	37.9	37.4	35.9
250	45.0	46.0	44.0	43.9	43.4	43.4	43.1	43.7	43.4	44.3
500	50.4	52.2	50.4	49.6	50.6	50.1	51.1	50.2	49.9	49.9
1000	57.2	59.5	59.3	60.5	58.8	57.9	57.3	60.5	60.5	58.8
2000	64.2	64.9	62.7	65.0	62.2	63.3	63.0	63.7	64.4	65.6
4000	64.4	63.1	62.7	68.8	65.4	62.5	62.9	62.4	62.6	61.1
8000	61.5	61.9	61.6	60.7	61.7	60.9	59.9	60.7	59.4	54.9

Table 5 *– A-weighted sound pressure level data of the drill across the points of the hemispherical configuration for the specified frequencies*

Frequency [Hz]	**1** *[dB(A)]*	**2** *[dB(A)]*	**3** *[dB(A)]*	**4** *[dB(A)]*	**5** *[dB(A)]*	**6** *[dB(A)]*	**7** *[dB(A)]*	**8** *[dB(A)]*	**9** *[dB(A)]*	**10** *[dB(A)]*
125	59.7	60.0	58.2	58.9	58.9	58.4	56.7	57.2	55.9	52.7
250	68.3	68.1	66.9	67.0	66.6	66.8	64.6	65.6	64.4	63.7
500	74.7	74.9	73.4	72.8	72.4	72.7	70.9	71.3	70.9	72.8
1000	79.9	79.9	77.8	78.9	79.2	77.6	79.6	80.1	79.8	81.6
2000	78.9	73.4	80.0	81.8	81.3	81.4	80.0	80.2	80.2	79.6
4000	78.8	79.0	77.0	78.1	77.9	77.6	76.4	76.3	75.9	73.5
8000	72.1	71.1	70.0	71.1	70.8	70.6	69.1	68.4	67.9	64.9

Table 6 *– A-weighted sound pressure level data of the reference sound source across the points of the hemispherical configuration for the specified frequencies*

Calculations

In order to understand the metrics employed in this study, this section will calculate the required descriptors in each of the methods to allow the sound power levels of each device in a semi-reverberant field to be observed.

The average surface sound pressure level, $\overline{L_{pm}}$, can be calculated using the Equation (1) from section 6.1 in the Australian Standards 1217.5:

$$\overline{L_{pm}} = 10log_{10}\left(\frac{1}{N}\sum_{i=1}^{n} 10^{0.1L_{pi}}\right)$$

Using 125 Hz as an example, the average surface sound pressure level for that frequency can be calculated as:

$$\overline{L_{pm}} = 10log_{10}\left[\frac{1}{10}(10^{3.94} + 10^{4.17} + 10^{3.86} + 10^{3.80} + 10^{3.87} + 10^{3.85} + 10^{3.78} + 10^{3.79} + 10^{3.74} + 10^{3.59})\right]$$

$$= 38.64\ dB(A)$$

Similarly, calculating for the other frequency bands, we obtain the following mean surface sound pressures for the drill in Table 7. Also, we undertake this same set of calculations for the reference sound source to yield the figures in Table 8, yielding the figures below:

Frequency	$\overline{L_{pm}}$ ***(Drill)***
[Hz]	*[dB(A)]*
125	38.64
250	44.11
500	50.50
1000	59.19
2000	64.03
4000	64.20
8000	60.65

Table 7 *– A-weighted mean surface sound pressures for the drill across the specified frequencies*

Frequency	$\overline{L_{pm}}$ ***(Reference Sound Source)***
[Hz]	*[dB(A)]*
125	58.07
250	66.44
500	72.89
1000	79.58
2000	80.10
4000	77.30
8000	69.99

Table 8 *– A-weighted mean surface sound pressures for the reference sound source across the specified frequencies*

From here on, the calculations for the Direct Method and Comparative Method diverge.

The Direct Method

Since these measurements were taken in a semi-reverberant field, the figures for A-weighted mean surface sound pressures need to be corrected to account for reverberation. To calculate the correction factor, K, for the reverberation experienced in these measurements, several variables must be considered.

$$K = 10\log_{10}\left(1 + \frac{4}{A/S}\right), where\ A = \frac{55.3V}{cT_{60}}$$

Where:

- K is the correction factor
- A is the Equivalent Sound Absorption Area, as defined by AS 1045
  - V is the volume of the reverberant room in *m^3*
  - c is the speed of sound in air at the ambient conditions of the room, in *m/s*
  - T_{60} are the reverberation times of each frequency band, by measurement, in *sec*
- S is the area enclosed by the hemisphere of the measurement configuration

Firstly, to calculating for A, we have to find V:

$$V = 12 \times 11 \times 6.5 = 858m^3$$

c is given to be 343 m/s at the ambient condition of the room. This means A equates to:

$$A = \frac{55.3 \times 858}{343 \times T_{60}} = \frac{138.3306\ldots}{T_{60}}$$

Table 9 gives the values of T_{60} across the frequencies considered, and the subsequent values of A:

Frequency	***T_{60}***	***A***
[Hz]	*[sec]*	*[m²]*
125	1.20	115.28
250	2.96	46.73
500	2.40	57.64
1000	2.81	49.23
2000	2.53	54.68
4000	1.89	73.19
8000	0.96	144.09

Table 9 *– Reverberation times and equivalent sound absorption areas for the frequencies specified*

Following on, the value for S is given as 6.28m^2.

Subsequently, the value of K can be calculated using the formula from above:

$$K = 10\log_{10}\left(1 + \frac{4}{A/S}\right)$$

This yields the following correction factors across the frequencies considered in Table 10:

Frequency	***T_{60}***	***A***	***K***
[Hz]	*[sec]*	*[m²]*	*[dB(A)]*
125	1.20	115.28	0.86
250	2.96	46.73	1.87
500	2.40	57.64	1.57
1000	2.81	49.23	1.79
2000	2.53	54.68	1.64
4000	1.89	73.19	1.28
8000	0.96	144.09	0.70

Table 10 *– Reverberation correction factors, with associated reverberation times and equivalent sound absorption areas for the frequencies specified*

Using the correction factors to adjust the measurements from Table 7 for the drill, the corrected figures can be calculated by the formula $\overline{L_{pf}} = \overline{L_{pm}} - K$. We are thence able to obtain the following reverberation-corrected figures in Table 11:

Frequency	***$\overline{L_{pm}}$ (Drill)***	***K***	***$\overline{L_{pf}}$ (Drill)***
[Hz]	*[dB(A)]*	*[dB(A)]*	*[dB(A)]*
125	38.64	0.86	37.78
250	44.11	1.87	42.24
500	50.50	1.57	48.93
1000	59.19	1.79	57.40
2000	64.03	1.64	62.38
4000	64.20	1.28	62.92
8000	60.65	0.70	59.96

Table 11 *– The corrected free field mean surface sound pressures for the frequencies specified*

The sound power levels can then be calculated using these corrected sound pressure levels, using the formula below:

$$L_W = \overline{L_{pf}} + 10\log_{10}\left(\frac{S}{S_0}\right)$$

S is the same as above, given as 6.28m^2; S_0 is the standardised unit area of 1m^2. This allows us to calculate the power levels displayed in Table 12:

Frequency	$\overline{L_{pf}}$ ***(Drill)***	L_W ***(Drill)***
[Hz]	*[dB(A)]*	*[dB(A)]*
125	37.78	45.76
250	42.24	50.22
500	48.93	56.91
1000	57.40	65.38
2000	62.38	70.36
4000	62.92	70.90
8000	59.96	67.93

The corrected sound power levels of the drill for the frequencies specified by the Direct Method

This concludes the Direct Method.

The Comparison Method

The comparison method requires a second sound source of which the characteristics are known to find the corrected sound power levels for each frequency. Referring back to Table 8, we have:

Frequency	$\overline{L_{pm}}$ ***(Reference Sound Source)***
[Hz]	*[dB(A)]*
125	58.07
250	66.44
500	72.89
1000	79.58
2000	80.10
4000	77.30
8000	69.99

Table 8 *– A-weighted mean surface sound pressures for the reference sound source across the specified frequencies*

These mean sound pressure levels can be used to calculate an uncorrected sound power level, using the formula:

$$L_{W,ref(uncorrected)} = \overline{L_{pm}} + 10\log_{10}\left(\frac{S}{S_0}\right)$$

The values of S and S_0 are the same as in the Direct Method, namely $S = 6.28\ m^2$ and $S_0 = 1\ m^2$. This allows us to calculate the power levels displayed in Table 13:

Frequency	$L_{W,ref(uncorrected)}$ ***(Reference Sound Source)***
[Hz]	*[dB(A)]*
125	66.05
250	74.42
500	80.87
1000	87.56
2000	88.08
4000	85.28
8000	77.97

Table 13 *– A-weighted uncorrected sound power levels for the reference sound source across the specified frequencies*

Corrected free field sound power levels were supplied by the B&K 4204 data sheet. These values would allow the correction of the uncorrected sound power levels, and are displayed below in Table 14:

Frequency	$L_{W,ref}$***, unweighted***	$L_{W,ref}$ ***A-weighted***
[Hz]	*[dB]*	*[dB(A)]*
125	80.5	64.4
250	82.4	73.8
500	82.6	79.4
1000	87.1	87.1
2000	86.9	88.1
4000	84.1	85.1
8000	80.7	79.6

Table 14 *– Free field sound power levels of reference sound source across frequencies specified*

The correction factor can then be calculated from the following equation:

$$K = L_{W,ref(uncorrected)} - L_{W,ref}$$

This allows us to calculate the environmental correction factors displayed in Table 15:

Frequency	$L_{W,ref(uncorrected)}$	$L_{W,ref}$	K
[Hz]	*[dB(A)]*	*[dB(A)]*	*[dB(A)]*
125	66.05	64.4	1.65
250	74.42	73.8	0.62
500	80.87	79.4	1.47
1000	87.56	87.1	0.46
2000	88.08	88.1	-0.02
4000	85.28	85.1	0.18
8000	77.97	79.6	-1.63

Table 15 *– Environmental correction factors calculated from the reference sound source across frequencies specified*

Using the formula $\overline{L_{pf}} = \overline{L_{pm}} - K$, we can calculate the corrected free-field average surface sound pressure level, in conjunction with the mean sound pressure levels of the drill found in Table 7. The results can be found in the Table 16 below:

Frequency	$\overline{L_{pm}}$ (Drill)	K	$\overline{L_{pf}}$ (Drill)
[Hz]	[dB(A)]	[dB(A)]	[dB(A)]
125	38.64	1.65	37.00
250	44.11	0.62	43.48
500	50.50	1.47	49.03
1000	59.19	0.46	58.73
2000	64.03	-0.02	64.04
4000	64.20	0.18	64.02
8000	60.65	-1.63	62.28

***Table 16** – Corrected free field average surface sound pressures across frequencies specified via the Comparison Method*

Similar to the closing stages of the Direct Method, the sound power level was calculated using the formula below, and values of $S = 6.28\, m^2$ and $S = 1\, m^2$.

$$L_W = \overline{L_{pf}} + 10\log_{10}\left(\frac{S}{S_0}\right)$$

Frequency	$\overline{L_{pf}}$ (Drill)	L_W (Drill)
[Hz]	[dB(A)]	[dB(A)]
125	37.00	44.97
250	43.48	51.46
500	49.03	57.01
1000	58.73	66.71
2000	64.04	72.02
4000	64.02	72.00
8000	62.28	70.26

***Table 17** – The corrected sound power levels of the drill for the frequencies specified by the Comparison Method*

This concludes the Comparison Method.

Discussion

Comparing the corrected sound power levels of the drill for the two methods undertaken, we obtain the figures found in Table 18 and graph of Figure 2. The total was calculated using the following formula:

$$L_{W,total} = 10log_{10}\left(\sum_{i=1}^{n} 10^{0.1L_{Wi}}\right)$$

Frequency	L_W (Drill)	L_W (Drill)	ΔL_W
[Hz]	[dB(A)]	[dB(A)]	[dB(A)]
125	45.76	44.97	0.79
250	50.22	51.46	1.24
500	56.91	57.01	0.10
1000	65.38	66.71	1.33
2000	70.36	72.02	1.66
4000	70.90	72.00	1.10
8000	67.93	70.26	2.33
TOTAL	**75.25**	**76.79**	**1.54**

***Table 18** – A comparative table of corrected sound power levels of the drill for the Direct Method vs. Comparison Method*

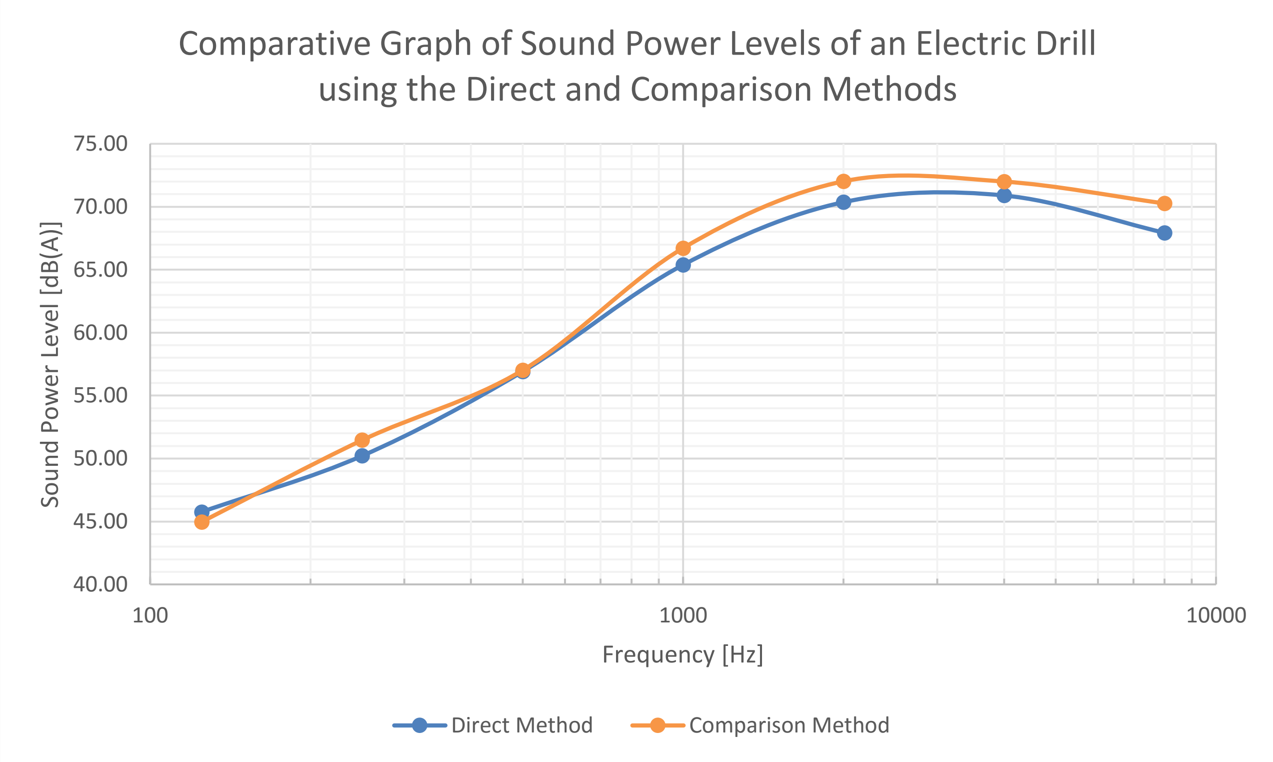

Figure 2 *– A graphical compare of corrected sound power levels of the drill for the Direct Method vs. Comparison Method*

The two methods have a closely aligned set of data points. The totals calculated in Table 18 differ by only 1.54 dB, with the largest difference being 1.66 dB at 2000Hz; these differences are acceptably minimal, suggesting that the procedure was carried out with a sufficient level of accuracy.

However, there are some differences - it is notable that the Direct Method has a smoother graphical line, against the Comparative Method, which has an extra point of inflection around the 250Hz data point, and a more acute apex from a little after 2000Hz. This can be attributed to the accuracy of the Comparison Method, which should be slightly less than the Direct Method, since two sets of measurements have to be taken, which exposes the method to more measurement-related errors (see below, "Errors"). That being said, the difference between the two methods is minimal enough to allow a reasonable degree of accuracy to be establish between both of these methods.

Errors

Even though the conditions of recording were standardised, some errors included:

- Measurement errors could have affected the accuracy of the measurements. The sound level meter was held by hand with an approximate 45° tilt, at a height that was measured by a tape measure. Both these sources of error could have affected the results. The coordinates marked on the floor of the hemisphere also had attributable measurement errors.
    - An improvement which could be made with regards to this source of error would include the use of a tripod with a higher scale of height and orientation control.

- The presence of people and other non-reflective surfaces of the room may have affected the measurements, due to different noise absorption and reflection properties. The formulae used in this investigation assumes the room has a rectangular-prismatic shape with no obstructions.
  - An improvement made in this respect could have used an empty, sealed room, with an externally controlled measurement system to remove the presence of people.
- The background noise of the building systems in the room of the recording may have affected the pink and white noise recordings.
  - This was mitigated by attempting to minimise the background noise before starting the recordings.

Even though these errors were present, the resultant figures and their close correlation showed that the effects of these errors were not substantial enough to significantly impact the results in a way which would impinge on the aims of the laboratory session.

5. Conclusion

The aims of this laboratory were achieved: the correct usage of sound measurement instruments were undertaken during the measurement of two sound sources in order to calculate the sound power level, adjusted for considerations in reverberation. Two methods were used to calculate the equivalent sound power level in a free-field – the Direct Method and the Comparison Method. These methods were contrasted and found to be very similar to each other, supporting the accuracy of the results from each method. This contributed to a better understanding of the methods which can be used to adjust for the effects of sound reflection in a semi-reverberant room.

End of Laboratory Report