Normal Incidence Sound Absorption Measurement of Circular Perforated Panels Using Sound Intensity Technique

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Abstract

It was ascertained that, sound intensity measurement based on fixed point scanning technique could be used to measure the normal incidence sound absorption (αN) of perforated panels accurately and reliably In this paper, the importance of sound field quality indicator (F_1, F_2, F_3, F_4) and sound intensity probe measurements distance toward measured αN reliability will be discussed. Individual statistical regression models that suit the measured αN for 20% and 30% perforation ratio were obtained. In addition, overall model for 20% and 30% perforation ratio were also obtained and can served as a basis for αN prediction of perforated panels with the same perforation ratio. The findings suggest, circular perforated panels, which are the simplest form of direct piercing carved wood panels (DPCWP) are able to act as sound absorber.

1.0 Introduction

Normal incidence sound absorption (αN) measurement of an acoustics materials using sound intensity technique was ascertained to be able to results in accurate and reliable αN [1][2]. This technique allows it to be used to measure αN of circular perforated panels, which is the simplest form of DPCWP. Knowing and able to predict the αN performance of DPCWP normally used as part of an enclosed room wall partition help toward achieving intended acoustics quality particularly its Reverberation Time (RT60). Earlier, the consideration of using DPCWP as part of wall partition is believed mainly on aesthetics consideration besides helping in natural ventilation to occur. Therefore, it is timely and appropriate, to enhance the applicability of the DPCWP beside its conventional applications.

2.0 Direct Piercing Carved Wood Panels (DPCWP)

Direct piercing carved wood panels (DPCWP) have been used as part of wall partitions for an enclosed room particularly in a mosque. This helps in providing natural ventilation as air can pass through the panel easily. At the same time, it is believed that the DPCWP are able to act as sound absorber. DPCWP are available in various perforation ratio, patterns and elements. The circular perforated panels are the simplest forms of DPCWP available.

Documented evidence suggest that, as early as 1793, the DPCWP have been used as part of a wall partition for a mosque as in Masjid Abidin, Kuala Terengganu, Trengganu [3]. The Mosque was build by Sultan Zainal Abidin II where, initially the mosque was build from wood. Subsequently it undergoes renovations to what it is nowadays.

The right wall partitions consist of 7 door panels with 4 doors leaves on each door panels (2 door leaves on each side). For each door panel, up to the height of 1m from the floor, there is a solid wood partitions, where after that height, the floral elements of DPCWP were used as part of the wall partitions. On the above of each door unit, there is a Calligraphy element of DPCWP that constitute part of the wall panel. The door is of flexible type, which can be, squeeze, open and closed easily. It is also observed that, the back wall partition consist of 4 door leaves, whereas another 2 door panels is of 8 door leaves with the same configuration as in the right side door panels. It is believed that, the used of DPCWP in this mosque is to help in achieving proper acoustic quality. This is taking into account sound energy can pass through the panels easily without reflecting back to the source Excessive sound reflections can cause speech signal interference and hence degrading speech intelligibility inside.

3.0 Probe Measurement Distance

Probe measurement distance from the material surface used in the measurement of sound intensity to calculate the measured αN is one of the factors that can contribute to the reliability of the sound intensity measured. It is considering whenever normal incidence sound field impinges on the acoustic material, the standing wave shall be created in front of the reflecting material surface. The sound pressure amplitude shall be minimum at λ/4, 3λ/4 etc from the material surface Probe positioning such as at λ/4 from the material surface shall results in easy sound field as indicated by its low Lpi value.

It is pertinent that, in actual sound intensity measurements, the thickness of the material should be taken into consideration to determine the actual probe measurement distance.

Table 1 : measurement distance for a 20mm material thickness

F(Hz)	250	500	1K	2K	4K
λ/4(mm)	340	170	85	43	22
Material thickness (mm)	20	20	20	20	20
mea.dist (mm)	320	150	65	23	2
0.75λ (mm)	-	-	-	127	64
Mea.dist (mm)	-	-	-	107	44
1.25λ (mm)	-	-	-	-	107
Mea.dist (mm)	320	150	65	107	87

Table 1 shows the measurement distance from 250Hz to 4 kHz. The probe positions were at 0.75λ and 1.25 λ respectively where another minimum sound pressure amplitude shall occur. These positions are predicted to result in easy sound field at its respected octave center frequency to results in reliable sound intensity measured.

4.0 Sound Quality Indicators

4.1 Surface Pressure Intensity Indicator (F_2)

$$F_2 = L_{pI} = L_p - |L_I| \qquad (1)$$

Where

$F_2 = L_{pI}$ = pressure intensity index (dB)

L_p = sound pressure level (dB)

$|L_I|$ = Sound intensity level (dB)

The calculation of F_2 = Lp1 does not taken into consideration the direction of L_I. Low L_{pI} value is an indication of easy sound field being measured. This translates into minimal phase mismatch error [4]. High L_{pI} value indicates difficult sound field is being measured where there is greater influence of phase mismatch error in the measurement. This will severely affect the accuracy of the sound intensity measured. Good sound absorption materials will results in low Lp1, whereas poor sound absorption material results in high Lp1.

4.2 Negative Partial Power Indicator - F3

F3 = Lp - L1 (2)

Where

Lp = sound pressure Level (dB)
L1 = sound intensity Level (dB)

Calculation of F_3 takes into account the magnitude of L_I. Any existence of -ve L_I (-ve sound intensity) indicates the measurement is conducted in the near field region due to the sound field circulation effect. Sound intensity measurement in this region will results in unreliable measured sound intensity as the net intensity measured shall be uniform (-ve or +ve intensity, depending on the probe orientation).

4.3 Field Non-Uniformity Indicator - F4.

This sound quality indicator, F_4 is an indication of the non-uniformity of the sound intensity measured over its measurement positions. Small F_4 value indicates the sound intensity measurement positions are considerably even. This translates into reliable sound intensity measurement. High F4 value indicates considerably uneven sound intensity was measured over its measurement position which results in unreliable measurements. Therefore, F4 value shall also be check in any sound intensity measurement. This particularly to examine the non-uniformity severity of the sound intensity measured.

4.4 Non-Stationarity - F_1.

F_1 is an indication of the variation on the sound source measured. This variation can influence the reliability of the sound intensity measured. Stable sound source is required, where F1 < 0.6dB will results in reliable sound intensity measurements. It is appropriate, before any sound intensity measurements are to be conducted, examining the value of F1 checks the variability of the sound source.

5.0 Experimental set-up

The circular perforated panel of different configurations with 20% and 30% perforation ratio were fabricated. The perforated panel dimension is 1.2 m * 1.2m with 20 mm thickness of Punah species and securely mounted into the mounting frame. The details of the perforated panels are as in Table 2.

Table 2: circular perforated panel configurations with 20% and 30% perforation ratio.

Sample	r(mm)	d(mm)	% perforation
S1	16	60	20
S4	20	75	20
S8	44	150	20
S2	20	60	30
S10	54	150	30

The sound intensity measuring system used consist of B & K Real Time Analyzer type 2144, sound intensity probe type 4181, sound intensity calibrator type 3541, sound power program type 5304 and B & K sound source type 4224.

The sound power program type 5304 allows sound intensity measurement based on discreet point measurement complying with ISO 9614-1[5]. The measurements were conducted inside the Anechoic Chamber, available at the Acoustics Laboratory, Electrical Engineering Faculty, UTM. The Anechoic Chamber dimension is 3.42 m * 3.42 m * 2.17 m. The sound source was located about 2 m from the material surface and radiating toward the center of the material surface under study.

6.0 Result Discussion

Table 3 & 4 show the αN measured for the various configuration of the perforated panel fabricated.

Table 3: αN for circular perforated panel with 20% perforation ratio

Sample/ F(Hz)	250	500	1K	2K	4K
S1	1.0	0.82	0.67	0.33	0.31
S4	0.97	0.83	0.60	0.30	0.33
S8	0.93	0.80	0.60	0.26	0.53

Table 4 : αN for circular perforated panel with 30% perforation ratio.

Sample/ F(Hz)	250	500	1K	2K	4K
S2	0.97	0.96	0.83	0.50	0.53
S10	0.94	0.87	0.79	0.36	0.58

Overall, the measured αN exhibits decay trend form low frequency to high Frequency. The αN measured is generally higher at low frequency and decreasing as the frequency of measurement increases. Furthermore, the αN is higher over its measurement frequency for 30% perforation ratio compare to 20 % perforation ratio. Further, it is observed that, for sample S8 and S10 where the aperture radius is significantly larger than aperture radius of S1, S4 and S2, there appear an αN dip at 2KHz which is 0.26 and 0.36 respectively for 20% and 30% perforation ration. However, at 4KHz, there is an increment in αN measured which is 0.53 and 0.58 respectively in comparison to the αN measured at the same frequency as in sample S1, S4 and S2.

6.2 Statistical Regression Model

Exponential and polynomial statistical regression models were explored using Statistical Analysis System (SAS) package to find out which regression model will better fit to the measured sound absorption performance [6]. In addition, overall statistical regression model for 20% and 30% perforation ratio were also investigated where the influence of independent variables such as frequency and perforation ratio toward sound absorption performance can be modeled. The fitness of the exponential model toward the measured αN is examined through various statistical test [6][7][8]. There are convergence criteria, asymptotic standard error for the estimated parameter, asymptotic 95% upper and lower confidence interval, asymptotic correlation matrix, residual plot, the value of Skewness and Kurtosis, steam and leaf distribution, and normal probability plot.

For the polynomial regression model, the fitness of the model toward the measured αN is determined by examining the statistical parameters which include model significant level, variable significant level, residual plot, Skewness and Kurtosis value, steam and leaf distribution , normal probability plot and its C (p) value. It was found out as tabulated in Table 5, generally the exponential model is better fit to the individual data except for the prototype S8 where polynomial model better fit to the data.

Table 5 : Individual statistical regression model for 20% and 30% perforation ratio.

Sample	%Perforation	Regression Model
S1	20	$S=1.05*e^{-0.00045*Frq}$
S4	20	$S=1\text{-}035*e^{-0.00046*Frq}$
S8	20	$S=1.11-0.00068*Frq$ $+0.00000013*(Frq)^2$
S2	30	$S=1.016*e^{-0.00022*Frq}$
S10	30	$S=0.934*e^{-0.00021*Frq}$

Further statistical regression model was investigated to obtained the overall regression model that better fit to all measurements data at 20% and 30% perforation ratio. Exponential and polynomial model were examined and the better-fit regression models are as in Table 5.

Table 6 : Overall model for 20% & 30% perforation ratio.

Perforation ratio	Overall model
20%	$Y=1.12\text{-}00062Frq+0.00000011(frq)^2$
30%	$Y=0.98*e^{-0.00021*Frq}$

Based on Table 6, sound absorption performance for circular perforated panel with 20% perforation ratio can be model using quadratic polynomial model. At 30% perforation ratio, the exponential model is the most suitable model, to model its sound absorption performance.

7.0 Conclusions

To results in credible αN measurements for perforated panels, it is crucial that probe measurement distance is position where the predicted sound pressure level is minimum at that measurement distance. The value of sound quality indicators of the measured sound intensity should be examined to ascertain the reliability of the measured sound intensity. Individual and group statistical regression models have been developed for circular perforated panel with 20% and 30% perforation ratio. This model serve as a basis to predict the αN performance of perforated panels with the same perforation ratio. Results show that, circular perforated panel can act as sound absorption material as predicted. The use of perforated panels as part of a wall partitions of an enclosed room will be able to help improving its acoustics quality particularly its RT60 beside its conventional applications.

8.0 References

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