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Selection of perforated panel absorber by predicting sound absorption coefficient

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Abstract: This paper helps to choose better acoustic perforated panel absorber while selecting absorbing material on basis of sound absorption coefficient. In many applications it is found perforated panel with a porous absorbent (Polyurethane foam material) is usually located behind the panel to add acoustic resistance for efficient sound absorption. In sound absorption process of PU foam material the characteristics of the sound absorption is depend on thickness, porosity, tortuosity and composite nature of the foam material. This paper is concentrating on thickness of absorbing material to choose better insulation. The testing of perforated panel absorber is done by using Impedance tube method and that results are verified by using equivalent electric circuit approach (EECA). In this paper different Samples of perforated panel absorber with varying thickness of PU foam material tested and verified.

Keywords: Perforated Panel, PU Foam Material, Impedance Tube, EECA

Introduction: The most conventional noise-isolation devices, such as composite panels, vehicle mufflers and industrial silencers, and more, usually consist of a barrier composed of a perforated facing backed with some porous material. This model includes the effect of diffraction phenomenon caused by impedance discontinuities of the boundary surface, which was disregarded in the past studies.

The perforated panel absorber mainly associated with different parameters like thickness and airflow resistivity of the foam material as well as thickness, radius of hole and perforation ratio of the perforated sheet. Whereas, thickness of the foam material is very important parameter to clarify the sound absorption performance of the sound absorbing material. The phenomenon of sound attenuation over the sound absorption material covered perforated facing absorber is very similar to sound absorption materials. The perforated facing on sound absorption material are commonly used for protection use only. So the perforated facing on sound absorption material absorber material may be more suitable used in outdoor environment. [1]

In general the foam materials consist of PU or Rockwool Foam for sound absorption and they are fireproof. Therefore they are widely used as sound absorption material in noise control engineering. However the structure of fibrous material is complicated and analysis is not easily performed. Such absorbers have many complex phenomenon that affect their performance. In large size ordinary perforated panels the purpose of perforated sheet is only for protection purpose. In order to consolidate the present study equivalent electrical circuit approach (EECA) and experimental evaluation is carried out. [2]

Equivalent Electrical Circuit Approach: In acoustic system analysis, the equivalent electrical circuit approach (EECA) is a popular method to evaluate the total acoustic impedance of the sound absorber. In this approach the acoustic pressure, particle velocity and acoustic impedance respectively analogous to the voltage, electrical current and electrical impedance. Jinkyo applied the approach to evaluate the total acoustic impedance of sound absorber and obtain the absorption coefficient based on EECA. The acoustic impedance of perforated plate and fibrous material may be simulated and described below. [3]

$$Z_p = \frac{\rho_0}{ø}\sqrt{8\,\nu\,\omega}\left(1+\frac{t_p}{2\,r}\right) + i\,\frac{\omega}{ø}\rho_0\left[\sqrt{\frac{8}{\omega}}\left(1+\frac{t_p}{2r}\right)+t_p+\delta\right]$$

Where,

ρ_0 - is the air density,

ν - is the kinematic viscosity of air (ν = 15 × 10^{-6} m^2/s) at room temperature,

ω - is the angular frequency,

i - is the $\sqrt{-1}$ imaginary number,

t_p - is the thickness of the perforated sheet,

r - is the radius of the perforated hole,

$ø = \pi r^2 / b^2$ Perforation ratio of the sheet,

δ = 0.85 (2r) f(ø) viscous boundary layer thickness of the perforated plate

b - hole pitch of the perforated plate,

$f(ø) = 1 - 1.47\sqrt{ø} + 0.47\sqrt{ø^3}$

For homogeneous and isotropic porous materials, the acoustic impedance of fibrous material may be determined based on a report of Delany and Bazley. The normalized surface acoustic impedance of the layer for locally material placed on hard wall may be determined from,

$$Z_m = Z \coth \gamma\, d$$

Where,

Z – Specific acoustic impedance of the absorbing material,

γ - Propagation constant in the absorbing material, in radian / m,

d – Thickness of layer, in meter,

For various absorbing materials the normalized material impedance Z and the propagation constant γ can be deducted from the flow resistance σ of the material by mathematical relationships using C and wave no k_0 as parameters:

$$C = \frac{\sigma}{\rho_0 f} \qquad k_0 = \frac{2\,\pi\,f}{c_0}$$

Where,

σ - is the air flow resistivity, in pascal second per square meter,

f – is the frequency, in Hertz,

ρ_0 - is the density of air (1.22 kg/m^3)

c_0 - is the speed of sound in air (343 m/s)

For fibrous material these relationship are: (Delany and Bazley's relationship)

$Z = (1 + 0.0571\, C^{0.754}) - i(0.087\, C^{0.732})$

$\gamma = k_0\,(0.189\, C^{0.595}) - ik_0(1 + 0.0978\, C^{0.7})$

To predict absorption coefficient by using above models one should know the air flow resistivity of porous material. If Air flow resistivity is known then the Z and γ can be found out and further normal incident sound absorption coefficient can be easily predicted. The total specific acoustic impedance Z_t of perforated facing on fibrous material may be expressed as:

$$Z_t = \frac{Z_p}{\rho_0\, c_0} + Z_m$$

Evaluation of a Normal Absorption Coefficient: The acoustic absorption coefficient of fibrous material covered with perforated facing can be obtained from the above resultant total acoustic impedance. The normal α_n may be evaluated based on following equation. [1, 2, 3]

$$\alpha_n = 1 - \left|\frac{Z_T - 1}{Z_T + 1}\right|^2$$

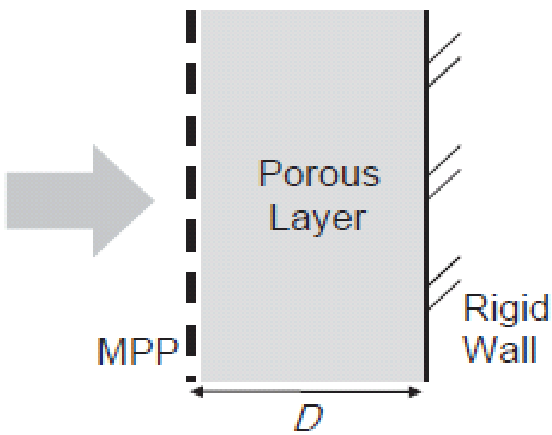

Fig 1: Geometry of a porous layer-backed single MPP absorber (left) and its electro-acoustical equivalent circuit model (right)

Calculation Method for airflow resistivity[4, 5]: The airflow resistivity " σ " is derived from the following relation:

Air flow resistivity (σ) is defined by:

$$\sigma = \frac{R_s}{d}$$

It is expressed in Pascal seconds per square meter.

Where,

Rs – is the specific air flow resistance, in Pascal second per meter, of the test specimen;

d – is the thickness, in meters, of the specimen in the direction of the flow

$$Rs = R\,A$$

It is expressed in Pascal second per meter.

Where,

R – is the airflow resistance, in Pascal second per cubic meter, of the test specimen;

A – is the cross sectional area, in square meter, of the test specimen perpendicular to the direction of flow.

$$R = \frac{\Delta p}{q_v}$$

It is expressed in Pascal second per cubic meter.

Where,

Δp - is the air pressure difference, in Pascal, across the test specimen with respect to the atmosphere,

q_v - is the volumetric air flow rate, in cubic meter per second, passing through the test specimen.

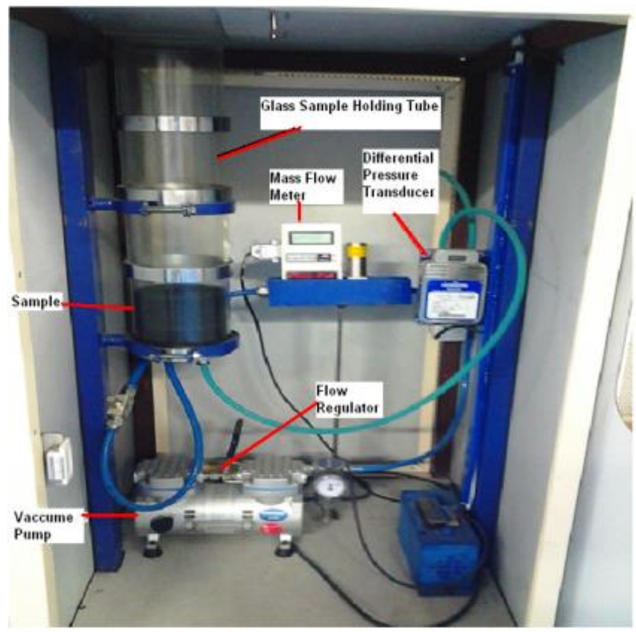

Fig. 2: Air Flow Measurement Test Rig

Experimental Measurement of Absorption Coefficients [6]: Testing has been performed to calculate sound absorption coefficient by using Impedance Tube Method. Four microphone impendence tube as per ISO 10354-2/ ASTM E-1050 is used for the experiment. This test method covers the use of impendence tube, two microphone locations and a digital frequency analysis system for the determination of sound absorption coefficient for normal incidence. The test method consists of sound source connected to one end and the test sample connected to the other end of the tube. In this method plane wave generated in the tube by a noise source and decomposition of the interference field is achieved by the measurement of acoustic pressure at two fixed location using wall mounted microphones or in the tube traversing microphone and subsequent calculation of the complex acoustic transfer function, the sound transmission loss and the impendence ratio's of acoustic material.

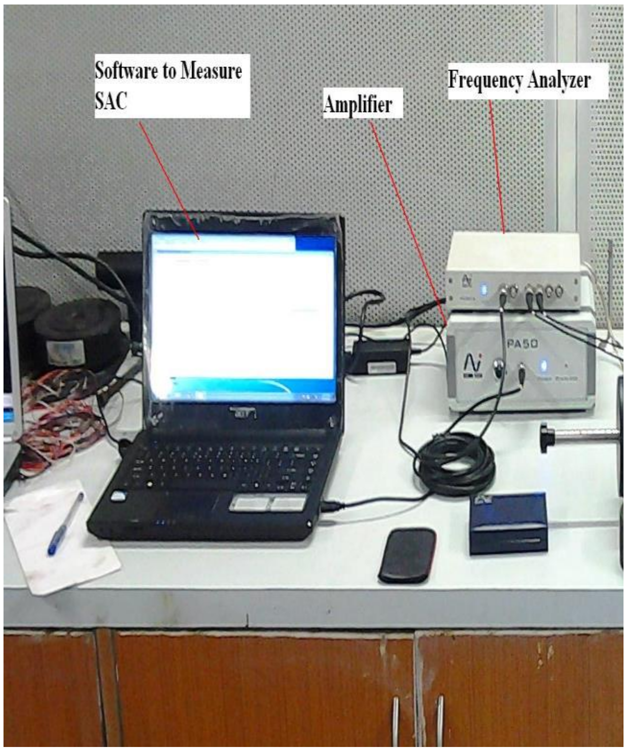

Fig.3: Impedance Tube Testing Set Up

Result Analysis: Comparison of absorption coefficient measured by impedance tube and calculated by MATLAB program for varying the thickness of porous material back cavity.

Variation in thickness of porous material cavity

Radius of perforated hole: **0.5 mm**, Thickness of sample sheet: **0.3 mm**

Pitch of the hole: **10 mm**

Varying thickness of porous material cavity: **50 mm, 75 mm & 100 mm**

Airflow resistivity: **13296 Pas/m^2, 11874 Pas/m^2& 5622 Pas/m^{2}respectively**

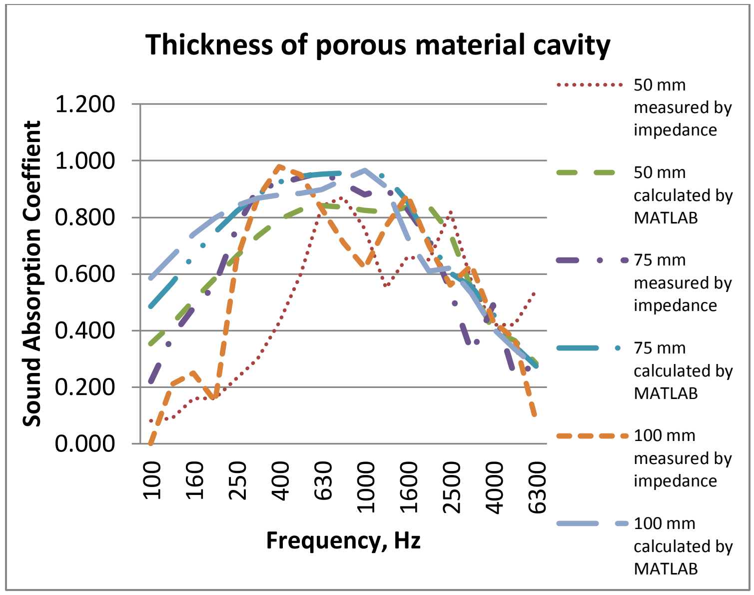

Fig. 4: Graph of SAC by varying Thickness of porous material cavity

1. The fig.4 gives the SAC values of different sound absorber for varying thickness of porous material by keeping other parameter constant. It reveals that on the basis of SAC values easily we can easily finalize optimum solution.
2. The fig.4 gives the details about experimentally and theoretically measured values of sound absorption coefficient for sound absorber by varying the thickness of porous material. On an average deviation observed between the all SAC values is **2-10 %.**
3. It reveals that there is maximum **10 %** average deviation between the actually measured and mathematically predicted SAC values foe all the samples.

In the perforated absorber with porous material back cavity, the sound absorption coefficient cover wide span over the all frequency range which can easily see by the graph obtained from proposed theory. Variation in a thickness of the porous material back cavity is a very important factor in this theory. As the thickness of the porous material back cavity increases, the higher values of absorption coefficient cover wide frequency range. Again it is depend on the airflow resistivity of the sound absorbing material like Foam, Rockwool and many more with varying thickness of the absorbing material. Variation in density responsible for the variation in sound absorption coefficient. Because if density of sound absorbing material varies its airflow resistivity also vary and if airflow resistivity increases range of sound absorption coefficient also increases.

In perforated plate backed by porous material due to squeezing of the sound wave, edge effect, vibration of the plate, interference and frictional & viscous losses inside the porous material. The absorption performance of the absorber is typically at high frequencies. The practical useful bandwidth is between 100 Hz and 3000 Hz. The absorption performance of porous absorber at high frequencies is normally declined if it is covered with perforated plate and remains constant at low frequencies. Compare with the experimental method the proposed theory is more reliable and general because it predict the absorption performance of perforated facing with porous absorber even if the diameter is too small.

Conclusions: The theoretical approach shows good agreement with the experimental results and maximum deviation observed within 10%. It means that the method employed to calculate sound absorption coefficient is validated and can be used further for predicting SAC of different sound absorber for the design of canopy as well as environmental acoustic applications. As thickness is increasing curve become more flat and sound absorption will be more. Since the proposed theory provides detail information of sound absorption of Perforated Panel absorber of different configuration, it can be used for design optimization of MPP absorber for environmental noise absorption application. It also improve understanding of the sound absorption performance of MPP absorber

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