ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 5, February 2016 in association with
HEERA COLLEGE OF ENGINEERING AND TECHNOLOGY, THIRUVANANTHAPURAM
Organizes
NATIONAL CONFERENCE ON ENGINEERING FOR LIFE (NCEL – 2016)
(12th -13th February 2016)

ACOUSTICAL ANALYSIS OF MULTILAYERED STRUCTURES

Ajish.P.S.
Department of Mechanical Engineering,
Sree Chitra Thirunal College of Engineering
Thiruvananthapuram-695018,Kerala,India

Prof. **M R Sarathchandradas**
Department of Mechanical Engineering,
Sree Chitra Thirunal College of Engineering
Thiruvananthapuram-695018,Kerala,India

Corresponding author.
Tel.: +91 9400757750. E-mail addresses: Ajishps.sree@gmail.Com

ABSTRACT
Multilayered structures like honeycomb sandwich structures, panels backed with various types of acoustic absorbers are widely used as sound barriers in many practical applications. Sound insulation now a days have become very indispensableespecially with aircraft fuselage, space crafts. The acoustical transmission loss for multilayered structures is carried out based on plane wave theory. The earlier studies obtained classical solution only up to three media and now classical solution is obtained for up to six media to find transmission loss in terms of dB based on normal incidence approach. The MATLAB is used to code the classical solution obtained , validated by resolving boundary conditions so as to reduce it to three media and also with available results.

KEYWORD: *Transmission loss, Acoustic Impedance, Plane Wave Theory, Finite Element Method, Classical Solution.*

1. Introduction

Sound is a form of energy that propagates through a medium as waves. As the sound travels in medium its intensity gets reduced which is quantified in terms of transmission loss. When sound travels from one medium to another the acoustic impedance mismatch of two media governs the transmission loss. For a given thickness of materials as the number of media through which sound travel increases the transmission loss also increases. So multilayered structures are now a days very widely used for sound insulation.

The classical solution to find transmission loss is only available up to three media [1].The same approach can be used to extend the formulation of classical solution up to n-media but as the number of media increases the formulation becomes more complex and difficult to solve. In most of the practical applications the number of media will alwaysbe three or more layers. In this particular study, it is aimed to develop a classical solution to find transmission loss for six media which can be effectively used to get transmission loss up to six media.

Xinjin Liu et.al [2] developed a general computational model for the sound absorption coefficients of multi-layer non-woven materials. Lauriks *et.al* [3] states acoustic materials are often regarded as homogeneous absorbers. Different Multilayer configurations are analyzed and experimental results of acoustic impedance and absorption are compared with those obtained by numerical simulations by Samir N. Y *et al*[4].

Nomenclature
n:Number of media n=1,2,3,4,5,6.
a_n,b_n,g :Arbitary constants
$(Pi)_n$:Incident wave sound pressure in different medium
$(Pr)_n$:Reflected wave sound pressure in different medium

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 5, February 2016 in association with
HEERA COLLEGE OF ENGINEERING AND TECHNOLOGY, THIRUVANANTHAPURAM
Organizes
NATIONAL CONFERENCE ON ENGINEERING FOR LIFE (NCEL – 2016)
(12th -13th February 2016)

$(Pt)_n$:Transmitted wave sound pressure in different medium
A_n :Incident wave complex sound pressure in different medium
B_n: Reflected wave sound pressure in different medium
k:Wave number of different medium, ω /c
c_n:Velocity of sound wave in different medium
f:frequency of sound wave
ρ_n:Density of different medium
ω:Angular frequency
r_n:SpecificAcoustic Impedance of different medium(ρ_n c_n)
l_n:Thickness of different medium.

2.Theory and Analytical Modelling

When the acoustic wave travels from one medium to another at the boundary because of mismatch of acoustic impedance (discontiniuty) reflected and transmitted waves are generated.The acoustic wave which is incident from one medium to another is at normal incidence at the boundary and transmission loss is calculated by taking the equation

$$\mathbf{TL = 20 \log \left[\frac{A1}{An(max)} \right]}$$

There are several approaches to find the trans mission loss in multimedia system,Statistical Energy Analysis for foam filled Honeycomb sandwich panels by Ran Zhou et.al[5],Generalized Matrix Method by Nelson et.al [6],Transfer Matrix Method for laminated glass Lee, C. Met.al,Numerical Characterization for honey comb sandwich Composite panels by Ahamed Abbadt et.al[8],Equivalent Circuit Method for lightweight multilayered curtains by Reto Pieren et.al[9].Eventhough there are several methods available to predict transmission loss for multilayered structures classical approach is the basic fundamental one.

The classical equation is based on the plane wave theory.The formulation is based on the following assumptions

1.Acoustic pressure on both side of boundary which separate adjacent media is same

2.Normal component of particle velocity across both side of boundary which separate adjacent two media are also same.

2.1 Transmission loss for six media

The derivation of classical equation for transmission loss in multilayered structure is employed by considering one – dimensional variation in a continuous medium .The sound travels through medium behavior is taken as reversible adiabatic process with constant mass particles. The fluctuations of pressure, density, and volume are very small. The pressure of sound wave is very less than static pressure of fluid. The steady flow velocity of fluid is much less than the propagation velocity of sound.

The incident wave,reflected waveand transmitted wave sound pressure when sound travel fron first medium to second is given by

$(Pi)_1=A_1e^{j(\omega\ t\text{-}k1l)}$
$(Pr)_1=B_1e^{j(\omega\ t+\ k1l)}$
$(Pt)_2= A2\ e^{\ j(\omega\ t\text{-}\ k1l)}$

Applying continuity of pressure and continuity of velocity at first and second medium the equilibrium equation of pressure and velocity can be deduced as

$(Pr)_1 + (Pi)_1 = (Pt)_2$
$(ui)1 + (ur)1 = (ut)2$

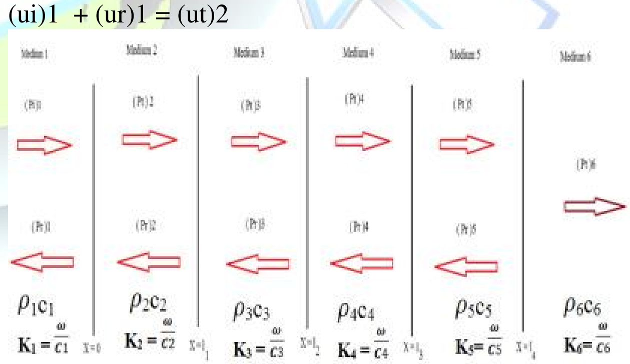

Fig 1.Six media diagram

By expanding the pressure term to complex pressure amplitude, velocity equation in pressure term and applying thickness of medium (l=0) the above equation will reduce as

A1+ B1=A2 (1)

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 5, February 2016 in association with
HEERA COLLEGE OF ENGINEERING AND TECHNOLOGY, THIRUVANANTHAPURAM
Organizes
NATIONAL CONFERENCE ON ENGINEERING FOR LIFE (NCEL – 2016)
(12^{th} -13^{th} February 2016)

r_2 (A1 – B1)= r_1 A2 (2)

Similarly we can write the solved equation for second, third, fourth, fifth, sixth media where thickness of medium are l_1,l_2,l_3,l_4,respectively as

$A_2e^{j(-k2l1)} + B_2e^{j(k2l1)} = A_3 + B_3$ (3)

$r_3(A_2\,e^{j(-k2l1)} - B_2\,e^{j(k2l1)}) = r_2(A_3 - B_3)$ (4)

$A_3e^{j(-k3l2)} + B_3e^{j(k3l2)} = A_4 + B_4$ (5)

$r_4(A_3e^{j(-k3l2)} - B_3e^{j(k3l2)}) = r_3(A_4 - B_4)$ (6)

$A_4e^{j(-k4l3)} + B_4e^{j(k4l3)} = A_5 + B_5$ (7)

$r_5(A_4e^{j(-k4l3)} - B_4e^{j(k4l3)}) = r_4(A_5 - B_5)$ (8)

$A_5e^{j(-k5l4)} + B_5e^{j(k5l4)} = A_6$ (9)

$r_6\,(A_5e^{j(-k5l4)} - B_5e^{j(k5l4)}) = r_5A_6$ (10)

solving (1) to (10) to find the $\frac{A1}{A6}$ pressure amplitude ratio of first media with the last mediais given by

$\frac{A1}{A6}$={(1/32)[a1.a2.a3.a4.a5.e^(k2.l1.j+k3.l2.j+k4.l3.j+k5.l4.j)+a1.b2.b3.a4.a5.e^(k2.l1.j-k3.l2.j+k4.l3.j+k5.l4.j)+a1.a2.b3.b4.a5.e^(k2.l1.j+k3.l2.j-k4.l3.j+k5.l4.j)+a1.a2.a3.b4.b5.e^(k2.l1.j+k3.l2.j+k4.l3.j-k5.l4.j)+a1.b2.a3.b4.a5.e^(k2.l1.j-k3.l2.j-k4.l3.j+k5.l4.j)+a1.b2.b3.b4.b5.e^ (k2.l1.j-k3.l2.j+k4.l3.j-k5.l4.j) +a1.b2.a3.a4. b5. e^(k2.l1.j-k3.l2.j-k4.l3.j-k5.l4.j) +a1.a2.b3.b5.e^(k2.l1.j+k3.l2.j-k4.l3.j-k5.l4.j)+b1.b2.a3.a4.a5.e^ (k2.l1.j+k3.l2.j+k4.l3.j+k5.l4.j) b1.b2.b3.b4.a5.e^(-k2.l1.j+k3.l2.j-k4.l3.j+k5.l4.j)+b1.b2.a3.b4.b5.e^(-k2.l1.j+k3.l2.j+k4.l3.j-k5.l4.j) +b1.a2.b3.a4.a5.e^(-k2.l1.j-k3.l2.j+k4.l3.j+k5.l4.j)+b1.a2.a3.b4.a5.e^(-k2.l1.j-k3.l2.j-k4.l3.j+k5.l4.j) +b1.a2.b3.b4.b5.e^(-k2.l1.j-k3.l2.j+k4.l3.j-k5.l4.j) +b1.b2.b3.a4.b5.e^(-k2.l1.j+k3.l2.j-k4.l3.j-k5.l4.j)+b1.a2.a3.a4.b5.e^(-k2.l1.j-k3.l2.j-k4.l3.j-k5.l4.j)] }

Then the equation for finding the transmission loss is given by

Transmission Loss=20.log10($\frac{A1}{A6}$)

Where a1=[(r2+r1)/r2],a2=[(r3+r2)/r3], a3=[(r4+r3)/r4],a4=[(r5+r4)/r5], a5=[(r6+r5)/r6],b1=[(r2-r1)/r2], b2=[(r3-r2)/r3],b3=[(r4-r3)/r4], b4=[(r5-r4)/r5],b5=[(r6-r5)/r6].

2.2Application of Six media equation to 5,4 and 3 media

The classical solution obtained for six media can be effectively employed to find the transmission loss for 5,4, and 3 media. For five media the six media equation is reduced by applying the boundary condition that the thickness of sixth media as zero and by ignoring the impedance value of sixth medium by taking a5,b5 as one. Christo Ananth et al. [7] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller. This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased. The further less number of media four and three media equation can be deduced by similar manner by considering thickness of fifth,fourth media as zero and by taking arbitary constants a5,b5, a4,b4, a3,b3 as one.

3.Validation of Formula Derived.

The equation developed is validated with both theoretical available equation and experimental results. The theoretical validation of the classical solution obtained is done by converting the six media equation reduced to three media and checking it with the already available equation.The experimental validation is done by checking the results obtained with the available experimental results .The equation developed is coded in MATLAB and the theoretical value for impedance ,thickness and velocity with which sound travels through the media are known then transmission loss for different frequency range can be obtained. The experimental values available for different multilayered structures are compared with the result obtained from classical solutions.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 5, February 2016 in association with
HEERA COLLEGE OF ENGINEERING AND TECHNOLOGY, THIRUVANANTHAPURAM
Organizes
NATIONAL CONFERENCE ON ENGINEERING FOR LIFE (NCEL – 2016)
(12th -13th February 2016)

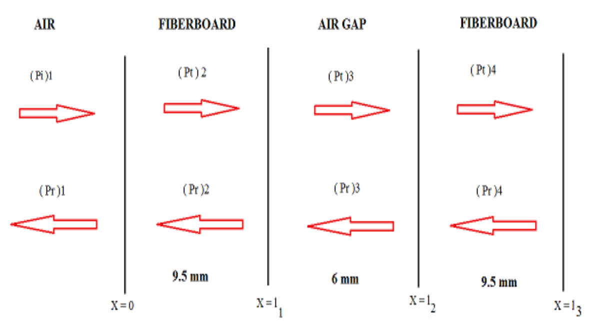

Fig 2.Double fiberboard panel diagram

Five media experimental results are obtained from Anoop R G et.al.[10].Here double fiberboard panel wih each layer of 9.5 mm thickness seperated by an air gap of 6 mm is considered.The sound is considered to be travelling from air medium to double fiberboard panel then to air.

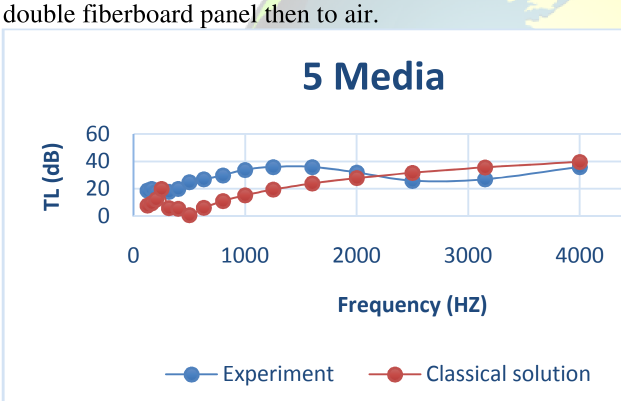

Fig 3. Five Media Transmission Loss

4. Conclusions

An expression for finding the transmission loss for multilayered structures up to six number of different media is developed. Comparison of developed equation with available theoretical expression and experimental results showed that the equation is a valid one.

5.References

[1]Kinsler, L., & Frey, A. (1962). Fundamentals of acoustics (2d ed.). New York: Wiley.

[2]Xinjin. Liu., Jianli. Liu., and Xuzhong. Su., " A computational model for the sound absorption coefficients of multi-layer non-wovens ," Textile Research Journal, Vol. 85(15) 1553–1564 , . 2015.

[3]W. Lauriks, A. Cops and C. Verhaegen.,Acoustical Properties Of elastic porous Materials,ELSIVER Journal of Sound and Vibration (1989) 131(l), 143-156.

[4]Samir N. Y., Gerges, Alessandro M. Balvedi Numerical simulation and experimental tests of multilayer systems with porous materials, ELSIVERApplied Acoustics ,58 (1999) 403-418.

[5]Ran Zhou, MalcolmJ.and Crocker.,Sound transmissionloss of foam filled honeycomb sandwich panels using statistical energy analysis and theoretical and measured dynamicproperties, ELSIVERJournal of Sound and Vibration, 329 (2010) 673–686 .

[6]B Nelson Edwin Charles and M R Sarathchandradas,'Generalized Matrix Approach For Design Of Single Expansion Reactive Mufflers',Proceedings of NCTT,CET,TVM,2004.

[7] Christo Ananth, M.A.Fathima, M.Gnana Soundarya, M.L.Jothi Alphonsa Sundari, B.Gayathri, Praghash.K, "Fully Automatic Vehicle for Multipurpose Applications", International Journal Of Advanced Research in Biology, Engineering, Science and Technology (IJARBEST), Volume 1,Special Issue 2 - November 2015, pp.8-12.

[8] Abbadi, A., Koutsawa, Y., Carmasol, A., Belouettar, S., & Azari, Z. (2009). Experimental and numerical characterization of honeycomb sandwich composite panels. Simulation Modelling Practice and Theory, 17(10), 1533-1547.

[9] Pieren, R., & Heutschi, K. (2015). Predicting sound absorption coefficients of lightweight multilayer curtains using the equivalent circuit method. Applied Acoustics, 92, 27-41.

[10]R. G. Anoop., and M. R. Sarathchandradas., " Study and Analysis of Sound Transmission through Multilayered Structures Using Generalized Matrix Method ". International Journal of Emerging Research in Management &Technology. ISSN: 2278-9359 (Volume-4, Issue-11).