Lightweight Vehicle Sound Package Treatments - Design and Simulation

Paresh Shravage
Alfa Acoustics, India

ABSTRACT

Today, technological evolution changing the automotive world very fast way. Vehicle manufacturers are willing to manufacture vehicles, which are lightweight, comfortable and less dependent on conventional fuels. When this type of phase transit happens, there is always a demand for new materials as well as new technologies. As the market is shifting from conventional fossil fuels to HEV/PHEV/EV or BEV, the demand for new lightweight sound packaging will also increase in a speedy way. In the past or even today, most of the vehicles are relying upon classical sound package treatments which are not only heavyweight but also having environmental problems. Ideally this transit from conventional to non-conventional fuel sources is beneficial for acoustic package manufacturers as earlier, they have meet stringent vehicle level noise targets in the low frequency region which was quite difficult for them. But because of this new technological shift, the noise targets are also shifting from low frequency region to mid to high frequency region due to usage of new powertrains or electric motor drives. This paper gives detail insights of classical as well as lightweight noise control sound package treatments used inside the passenger vehicles. It also discusses some the innovative ideas for achieving very good sound absorption in mid and high frequency region. It will also shade some light on configurations and design of these lightweight sound package treatment and predicting acoustic performance in terms sound absorption and sound transmission loss using Biot parameters.

INTRODUCTION

In present scenario, design and development of sound package materials is becoming very crucial in vehicle development and manufacturing process. Classical sound package treatments used inside vehicles are designed to reduce powertrain noise which is most dominant noise source in the low frequency region, an area where most of the sound package materials are less effective because of their thickness. To overcome this problem, sound package treatments are used in combination with other acoustic materials or sometimes with barrier materials like EVA/EPDM/PVC to improve its NVH properties. Due to this practice most of the times, weight of the sound package treatments was increasing beyond defined weight targets of a sound packaging resulting in a deterioration of vehicle mileage. Now due to technological evolution in vehicle manufacturing process, electric motors are taking place of powertrains. In such cases, the overall noise level of a vehicle will down [1,2]. This is an advantage for sound package engineers as not only noise level targets are coming down but also the region of noise also getting shifted to mid-high frequency side. Because of this shift in noise as well as frequency region, whole noise spectra will now in the area where sound package materials are more effective. Apart from this, as an electric motor is replacing classical powertrains, secondary noise sources such as wind noise, Tire/road noise, Ancillary system noise, etc. will become more dominant. So now NVH engineers have to work on multiple noise sources and design the sound package treatments accordingly so that the noise level should also remain below defined target level and at the same the time, overall weight of the complete sound package treatment also remain below weight target defined for vehicles. Due to this, acoustic material manufacturers will also face a challenge to manufacture low density, nature friendly acoustic materials as earlier, density of the sound package materials was also playing a huge role in governing overall NVH performance of a vehicle. This paper not only discusses lightweight sound package treatments but, also gives an insight on overall design process of these lightweight sound package treatments using intrinsic physical-Biot parameters for each layer for various applications inside a vehicle [3,4]. Apart from this, paper will also have an elaborative discussion on secondary noise sources which are becoming dominant in electric vehicles due to change in vehicle driving mechanisms along with innovative lightweight noise treatment solutions to cater these noise sources.

SOUND PACKAGING: ICV – HYBRID TO ELECTRIC VEHICLES

Today performance of modern vehicles is recognized by their NVH comfort, which is in terms governed by sound package treatments applied inside a passenger vehicle. A typical IC Engine / Hybrid vehicle consists of a dash insulator which separates engine and passenger compartment and at the same time it serves as a passage for steering wheel, brake and clutch components etc. through grommets. Depending upon vehicle type, the dash includes a heavy layer which helps in improving sound transmission properties of dash insulator in diesel vehicles. A vehicle carpet also plays a similar role, which reduces tire / road noise entering inside the passenger compartment and again depending upon vehicle it also consists of a heavy layer or other barriers. Figure 1 below shows typical internal structure of various sound package treatments used in today's vehicles along with similar lightweight treatments which can or will be replaced in near future.

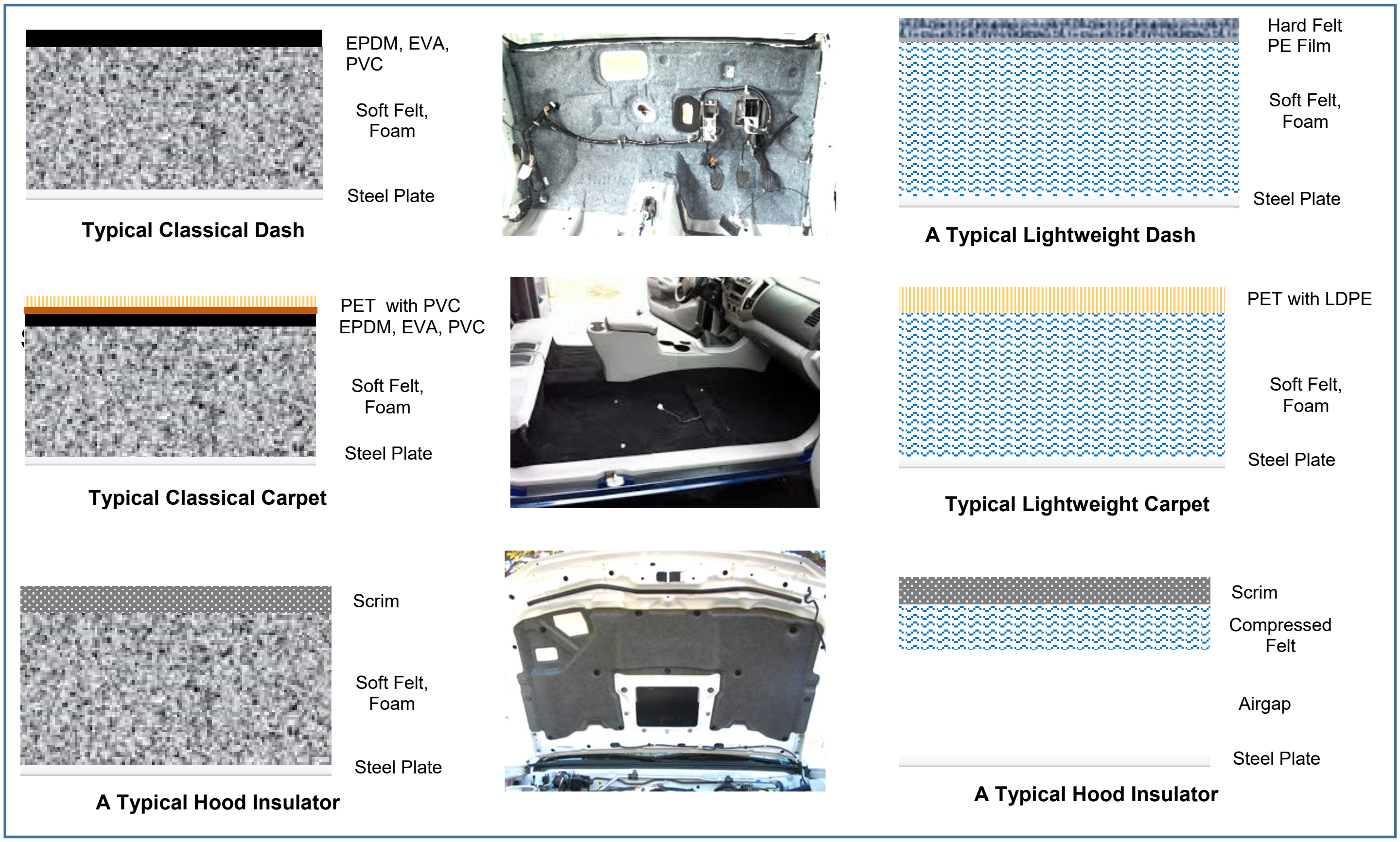


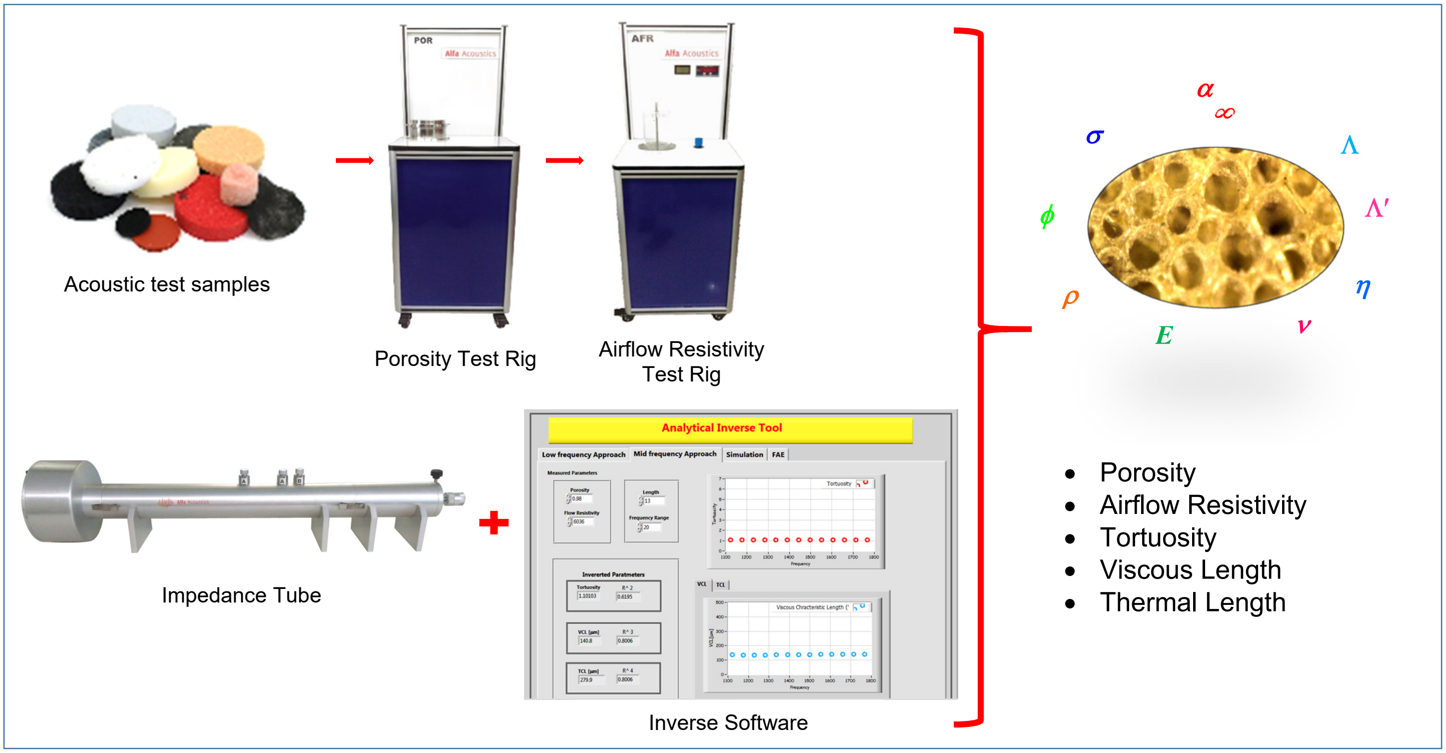
Figure 1. Typical Sound Package Treatments with Internal Structure

In electric vehicles, powertrain is completely replaced by electric motor there by directly reducing overall interior as well as exterior noise levels. Also the noise of the electric motor is so low that, most of the sound package treatments can be redesigned or replaced with very lightweight materials with better or higher acoustic performance. The second advantage of electric motors is their noise spectra, which mostly falls in the range of mid to high frequency area where most of the present acoustic materials alone or with combination give better acoustic performance compared to powertrain noise spectra which is mainly concentrated in low frequency region. This is the region where sound package materials fail to deliver expected acoustic performance due their space constrained thicknesses. To overcome this problem most of the times, engineers have to use sound package materials in higher densities along with permutations and combinations of different types of sound absorbing and insulating materials to match the acoustic performance which at the end, also results into increase in overall weight of sound package treatments and affecting vehicle mileage of a vehicle. Also most of the times engineers are finding it challenging task as, sometimes there is a dual performance requirement of sound absorption and sound insulation inside vehicles due to higher noise levels inside vehicles.

BIOT PARAMETERS

Acoustic performance of sound package materials is governed by Biot parameters of each layer. Based upon type of material frame; porosity, airflow resistivity, tortuosity and viscous as well as thermal length form a set of five physical parameters and are more than enough to model a rigid frame material. For limp type frame material, five physical intrinsic parameters along with density are required. While Young's modulus, Poisson ratio and loss factor are mechanical parameters which along with density and above physical parameters are required to model elastic frame material. Characterization of sound package materials require specialized test instruments. Out of nine parameters, porosity can be easily measured using a setup based upon Boyle's law [5]. Airflow resistivity is measured using an airflow meter as per ISO 9053 / ASTM C522 [6,7]. Measurement of tortuosity along with viscous and thermal length require ultrasonic test setup, but because of cost and errors induced by ultrasonic measurements, inverse techniques are becoming more popular in material characterization [8]. Inverse characterization of sound package materials requires, measurement of sound absorption coefficient along with its surface properties is a pre-requisite. Then this measured data is given as an input to the curve fitting software to get five physical parameters [9].

The inverse characterization software is based on the equivalent fluid model (Johnson-Champoux-Allard) which requires five macroscopic intrinsic parameters of the porous materials for mathematical modelling [10]. While in Lafarge's Model, one more parameter in addition to above mentioned parameters is required. It is known as thermal permeability as an effect of thermal dissipation at higher frequencies. In these two models the frame of the material is assumed to be rigid, i.e. motionless and the so only one wave can propagate through the material. The inverse characterization of the parameters is performed over a wide frequency range [50-4200 Hz] [11]. The test specimen is backed by the rigid end termination of the three microphone tube. The Below schematic shows test rigs required for porosity and airflow resistivity measurements along with flow chart for inverse characterization.



Measured Parameters
Porosity 0.98
Flow Resistivity 6036
Length 13
Frequency Range 20

Inverterted Paratmeters
Tortuosity 1.10103 R^ 2 0.6195
VCL [µm] 140.8 R^ 3 0.8006
TCL [µm] 279.9 R^ 4 0.8006

- Porosity
- Airflow Resistivity
- Tortuosity
- Viscous Length
- Thermal Length

Figure 2. Typical Sound Package Treatments with Internal Structure

Mechanical characterization of sound package materials requires quasi-static mechanical analyzer which gives set of all three mechanical parameters. In the experimental set up, the sample is sandwiched between two rigid plates. The lower plate is excited by electrodynamic shaker and upper plate is fixed rigidly. During the measurement, the lower plate is excited and because of this the sample gets deformed along its diameter. This effect is also known as "bulge effect". This lateral deformation and the vertical deformation are measured by a laser vibrometer. Also the force exerted by the sample is measured by Force transducer. Using these quantities, it is possible to calculate transfer function and mechanical impedance, which are complex and frequency dependent. From these quantities, mechanical properties are calculated using finite element simulation of static case of porous sample under investigation [12].

LIGHTWEIGHT SOUND PACKAGES

Dash Insulator

Dash Insulator is an integral part of ICV and Hybrid vehicles. It separates engine compartment from passenger compartment. It consists of a steel plate along with different types heavy layers along with decoupler depending upon type of a vehicle either gasoline or diesel. The thickness of dash is 20-25 mm along with steel plate. Most of the dash insulators consist of heavy layers like EVA/EPDM ranging from 2000 - 6000 GSM while decoupler GSM starts from 600 to 2000 GSM. These layers along with steel plate makes mass-spring-mass effect resulting in an increase in sound transmission loss by 18dB/Octave. The design of dash insulator starts from proper selection of layers required to meet the acoustic targets. The figure below shows effect of different configurations of dash insulators on sound absorption and sound transmission loss levels. The results are simulated for sample size of 1.2 m^2 to meet standard requirements of SAE J2883- Measurement of sound absorption coefficient in a small reverberation chamber and ASTM C2249 / ISO 10140 or ASTM E90 – Measurement of sound transmission loss of building partitions and elements [13,14,15,16]. The physical and mechanical parameters considered for simulation are given in table 1. The simulation software is based upon well-known transfer matrix methods.

Material	*Thickness*	*Density*	*Porosity*	*Airflow Resistivity*	*Tortuosity*	*VCL*	*TCL*	*Young's Modulus*	*Poisson Ratio*	*Loss Factor*
Unit	*d [mm]*	ρ [kg/m^3]	ϕ [-]	σ [Ns/m^4]	α_∞ [-]	$\wedge$ [μm]	$\wedge'$ [μm]	E [N/m^2]	ν [-]	η [–]
Hard Felt	4	300	0.93	100000	2.2	80	80	-	-	-
Soft Felt	20	48	0.95	15000	1.2	60	100	-	-	-
EVA	2	2000	-	-	-	-	-		0.2	0.01
Scrim	0.5	30	0.95	1000000	-	-	-	-	-	-
Steel Plate	0.8	7800	-	-	-	-	-			0.001

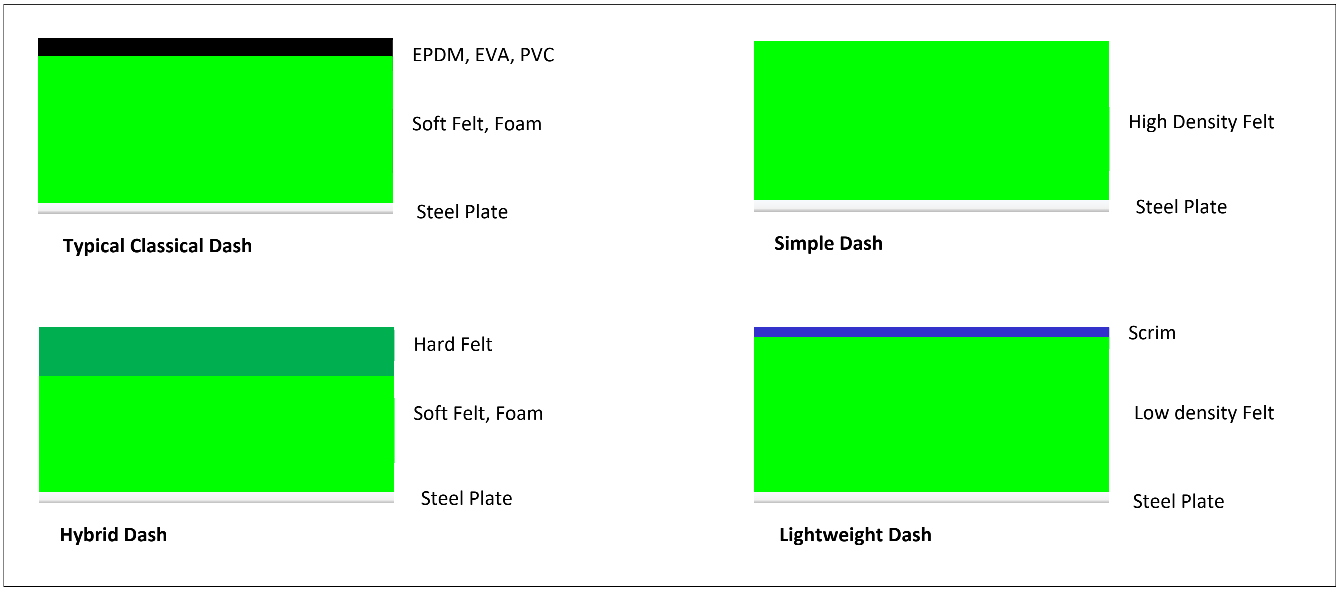
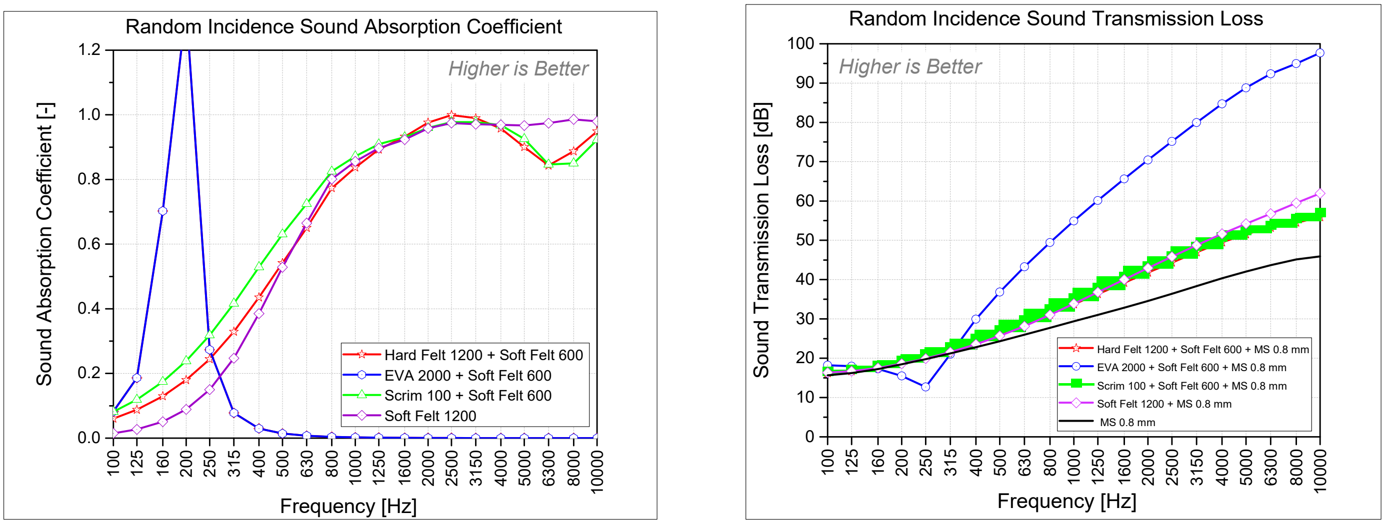


Figure 3. Layer wise configuration for different dash insulators

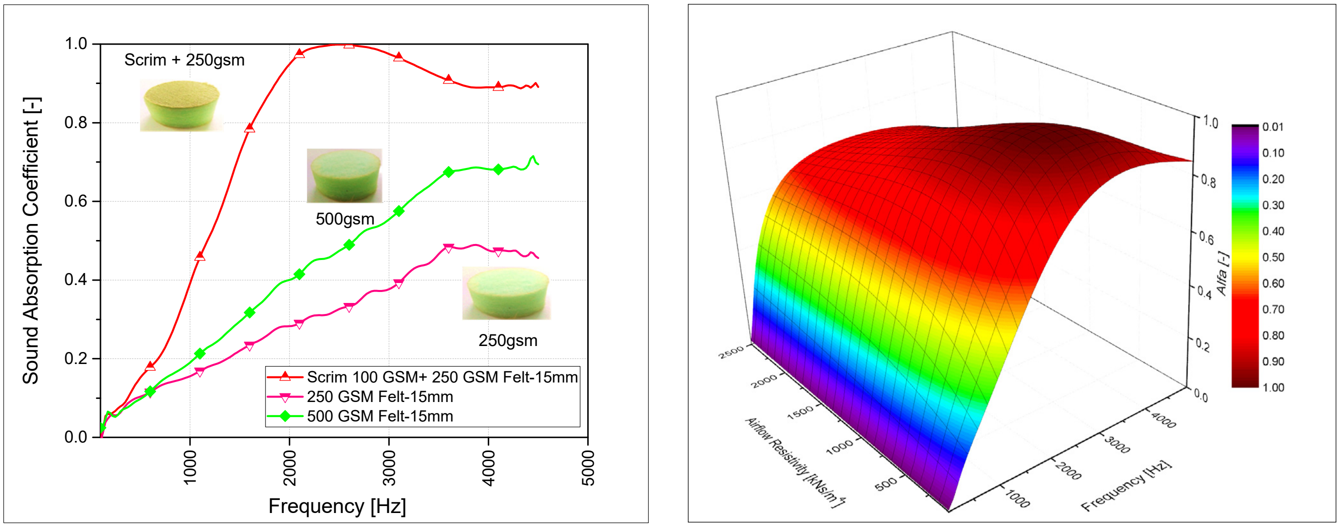
Figure 3 shows layer wise structure for different dash insulators discussed in this paper. Figure 4(a) shows random incidence sound absorption coefficient for classical dash insulator consisting EVA as a barrier, due to mass spring effect, the configuration shows prominent absorption at particular frequency in low frequency region, same configuration in figure 4(b) gives very good sound transmission loss except in low frequency region, where sound transmission loss decreased due to mass spring effect.



(a) (b)

Figure 4. Effect of Acoustic layers on different dash insulators

The second dash configuration is a hybrid configuration, in which acoustic performance was compensated with weight of the dash. In this configuration, absorption has increased significantly due to porous nature of the complete configuration while there is reduction in sound transmission loss. These two configurations mentioned above are widely used in ICV/HCV Vehicle due to their high noise signatures. The third dash discussed is with a high resistivity porous scrim using which it is possible to achieve similar sound absorption and transmission loss as in hybrid dash using more than 50% weight reduction in overall weight of dash insulator. This is more elaborated by following figure 5(a).



(a) (b)

Figure 5. Effect of Effect of Resistive Scrim on Sound Absorption

Figure 5(b) shows, simulation results for effect of high resistive scrim on sound absorption coefficient. In this case, airflow resistivity was increased linearly from 50000 to 2500000 Ns/m^4 and effect of increase in AFR is depicted in figure 5(b). This drastic increase in sound absorption coefficient is an effect of sudden impedance mismatch between resistive scrim and soft felt.

CONCLUSIONS

From this study, it is clear that, it is possible to design lightweight sound package treatments for ICH/HCV/EV vehicles using different types of acoustic layers. In this paper only, dash is considered for discussion but similar methodology can be successfully applied to carpet, wheel arch liners, which will play major role in EV as tyre noise will become dominant source of noise in them.

REFERENCES

1. Klaus Genuit, “Future Acoustics of Electric-Vehicle”, SAE International, 2012-36-0612, 2012
2. Gerd Marbjerg, “Noise from electric vehicles –a literature survey”, COMPETT Programme, 16th april 2013
3. M.A. Biot, 1956, Theory of propagation of elastic waves in a fluid saturated porous solid, I Low frequency range, II. High frequency range, J. of Acoust. Soc. of Am., **28**,168-191.
4. Song B.H. and Bolton S.J., “A transfer matrix approach for estimating the characteristic impedance and wave numbers of limp and rigid porous materials”, Journal of Acoustical Society of America, 107, 1131-1151, 2000
5. Y. Champoux, M.R. Stinson, G.A. Daigle, 1991, Air-based system for the measurement of porosity, J. of Acoust. Soc. of Am., 89, pp. 910-916.
6. ISO 9053, “Acoustics -- Materials for acoustical applications -- Determination of airflow resistance”, 1991
7. ASTM-C522, “Acoustics-Materials for acoustical applications-Determination of airflow resistance”, 1991
8. Allard J. F., Castagnède B., Henry M. and Lauriks W., “Evaluation of the tortuosity in acoustic porous materials saturated by air”, Review of Scientific Instruments **65** pp. 7654-755, 1994.
9. Paresh Shravage, Paolo Bonfiglio, Francesco Pompoli, “Hybrid Inversion technique for predicting geometrical parameters of Porous Materials”, Proc. of Acou. 08, June 29- July 04, Paris France, 2008
10. J. F. Allard, Y. Champoux, 1992, New empirical equations for sound propagation in rigid frame fibrous materials, J. of Acoust. Soc. of Am., **91**(6), 3346-3353.
11. ASTM E1050, “Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System”, 2012
12. E. Mariez, S. Sahraoui, and J. F. Allard, ‘‘Elastic constants of polyurethane foam’s skeleton for Biot model,’’ Proceedings of Internoise 96, (1996)
13. SAE J2883, “Laboratory Measurement of Random Incidence Sound Absorption Tests Using a Small Reverberation Room”, SAE Standard Committee
14. ASTM E2249, “Standard Test Method for Laboratory Measurement of Airborne Transmission Loss of Building Partitions and Elements Using Sound Intensity”, 2008
15. ISO 10140-2, “Laboratory measurement of airborne sound insulation of building elements”, 2010.
16. ASTM E90, “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements”, 2004

CONTACT

Dr. Paresh Shravage is Founder and Technical Head of Alfa Acoustics-a private R&D and consulting company. He has done his doctorate in Acoustic Materials from University of Pune, India. During his Doctorate, he has also worked as a Marie-Curie Fellow at School of Acoustics, University of Ferrara, Italy under European Doctorate in Sound and Vibration (EDSVS) programme. He is having almost 10 years of research and industrial experience in Acoustic materials, Noise and Vibration. He is also consulting as a Principal Scientist, NVH for L&L Products Pvt. Ltd.

He has published several research papers on acoustic materials in national / international conferences and journals. He is a recipient of Sir C.V. Raman award from the Acoustical society of India for his work on Reverberation chamber. During his service at ARAI, he was recognized by Innovation Awards several times.

He is a member of Acoustics Material Standard Committee, SAE International, USA and several other Institutes. His main area of specialization is development, characterization, simulation and Testing of acoustic materials for vehicle as well as building acoustics applications.

Email- alfa@alfaacoustics.com ; info@alfaacoustics.com , www.alfaacoustics.com