Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 101 (2016) 598 – 605

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

Automotive materials: an experimental investigation of an engine bay acoustic performances

D. Siano[a]*, M. Viscardi[b], M. A. Panza[a,b]

[a]Istituto Motori – CNR, Via Marconi 4, 80125 Naples, Italy

[b]Department of Industrial Engineering, University of Naples "Federico II", Via Claudio 21, 80125 Naples, Italy

Abstract

In this work an extensively experimental analysis aimed to verify the sound insulation properties of the engine bay of a commercial passenger car is carried out, evaluating the possibility to adopt different sound absorbing materials, to be applied under engine cover nylon skin, in the place of commonly used polyurethane foams. Experimental tests were performed on the vehicle at different stationary operating conditions, employing typical pressure microphones for far field measurements, according to the related prescribed standards. A limited number of materials has been initially selected through a preliminary analysis, and then employed for creating different engine cover configurations, which were subsequently tested in real engine operating conditions. For a good understanding of the obtained results, an experimental investigation through an innovative in situ impedance method aimed to assess acoustic properties of each considered material has been also performed. Among all the tested materials, only one able to ensure better acoustic performance at mid and high frequencies with respect to the already existing cover configuration, has been finally identified, after considering other selection criteria such as an adequate high temperature resistance and the most cost-effective solution. Future analyses will regard investigations on the use of additional materials, for solving problem in attenuating engine noise also at low frequencies.

Peer-review under responsibility of the Scientific Committee of ATI 2016.

Keywords: Acoustic radiation; engine compartment; far field; sound absorption; in situ impedance method.

1. Introduction

Nowadays, the acoustic comfort of a vehicle represents one of the most important aspects of overall quality, since it considerably affects customer's impression and judgment about. In the field of vehicle acoustic, although exterior noise plays a significant role, the major focus is on interior noise which is influenced by many sources [1]. Of course, the engine and power-train act as one of the primary excitation sources, together with road noise and wind noise. Hence, in the last years, many car manufacturers are investing in technologies able to provide noise and vibration control from the engine compartment to the passenger cabin. With this regard, proper sound treatments are developed in order to reduce vehicle interior noise and improve occupants comfort.

* Corresponding author. Tel.: +39-081-7177108.
E-mail address: d.siano@im.cnr.it

Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.076

There are essentially two different treatments for solving noise and vibration problems. While barriers and absorbers are used for air-borne noise problems, dampers are used for structure-borne noise problems. More in detail, an absorber is a material that reduces sound wave reflections from hard surfaces, dissipating sound as heat energy. Typically, it is either a fibrous or cellular material that presents both porous and elastic properties. A barrier is a component able to stop sound propagating from one area to another where noise reduction is desired. A barrier is a nonporous, massive and limp material. Generally, the more mass in a panel, the better its ability in avoiding the noise passing through. Secondly, a damper is used to absorb vibrational energy from resonating panels in a direct analogy to sound absorbers interacting with noise in the air. By absorbing energy, a damping material reduces the structure-borne noise radiated from the system to which it is applied.

Dashboard component usually is made of materials acting in controlling noise in a vehicle [1, 2, 3], but unfortunately it results to be insufficient in controlling noise propagation from the engine inside the passengers cabin, as it usually presents holes and cutouts for allowing different accessories to pass through. For this reason, noise leakage paths are introduced between engine compartment and cabin. Therefore, in order to achieve proper acoustic targets, part of the effort is also oriented directly at the engine. In this sense, a significant interest is paid by the automotive industry on the development of increasingly performing engine cover solutions, which in addition to work for a positive thermal management of the engine, have also to ensure noise reduction isolating engine vibrations. Generally, a conventional engine cover is composed by two parts: one is made of polyurethane foam material properly printed to follow the engine block shape, and another is a plastic component with an attractive surface appearance. The resulting trim panel thanks to its sound-absorbing and vibration-dampening qualities reduces engine noise level, improving passengers acoustic comfort.

Global competition is leading car manufacturers to consider the use of increasingly low-cost materials for noise control in a vehicle, which ensure at the same time increasingly high vibro-acoustic performances. To this aim, present work is exactly focused on exploring the use of different acoustic materials for noise control in a vehicle, in particular aimed in engine noise radiation. For this purpose, an experimental campaign has been performed at different rpm vehicle speed by acquiring noise radiation from a diesel vehicle chassis equipped with the original cover [4, 5]. Specifically, once the original engine cover has been characterized in terms of noise abatement, different engine cover configurations have been taken into account by replacing each time the polyurethane foam with various materials commonly used in automotive field, in order to test their performances directly on vehicle at different engine operating conditions. Noise acquisitions have been carried out in far field conditions, making use of typical pressure microphones positioned at fixed distances from the engine bay. Then, in order to get accurate information about acoustic properties of the tested materials for the engine cover, a more innovative pressure-velocity in situ impedance method has been used, too. Among all the tested materials, even if no substantial improvements in terms of Overall Noise Level have emerged, a better noise reduction behavior has been found at mid and high frequencies only for one of the considered materials, which could ensure moreover a lighter and less expensive solution with respect to the already existing one.

Nomenclature

EFR	Engine Firing Rate
OL	Overall Level
PA	Polyamide

2. Experimental activity

Experimental tests were carried out on a passenger car powered by a compression ignition engine. In particular, measurements of engine radiated noise were performed according to the ISO 3744 standard [6], which specifies methods of accuracy grade 2 (engineering grade) for determining the sound pressure levels at prescribed microphone positions around a noise source. The test environments in accordance with the above mentioned International Standard normative can be located indoors or outdoors, with one or more sound-reflecting planes present on or near which the noise source under test is mounted. The ideal environment is a completely open space with no bounding or reflecting surfaces other than the reflecting plane(s) (such as that provided by a qualified hemi-anechoic chamber), but procedures are given for applying corrections in the case of environments that are less than ideal. In this case acoustic data were acquired outdoors, with one hard reflecting surface (the ground), by using two typical microphones for far field measurements, properly located. More in detail, two PCB ICP® 1/4" free-field microphones were positioned with a slope of about 45° relative to the vertical of the engine top face, at a distance of 0.5 and 1 meters from the engine top surface. According to the experimental layout schematically reported in Fig. 1, acoustic signals were collected by using LMS SCADAS III multi-channel acquisition system, and then properly post-processed in LMS Test.Lab software, in terms of frequency spectra and overall levels.

Tests were performed at three different stationary engine operating conditions by using pedal accelerator being caution to reproduce a quasi-stationary rpm condition:

- minimum rpm (idle condition)

- 1500 rpm
- 2000 rpm.

Data logging time was set to 20 seconds per each test. For avoiding possible errors due to variations of gas pedal angle during the acquisition time, measurements were executed twice for each investigated condition and mean results have been utilized for the analysis.

Fig. 1. Experimental layout – location of the microphones.

Acoustic data were firstly acquired for the real engine bay with and without cover. In fig. 2 is reported the original configuration of the cover. While the bottom part is constituted by a flexible polyurethane foam component, the front side material presents a rigid plastic skin.

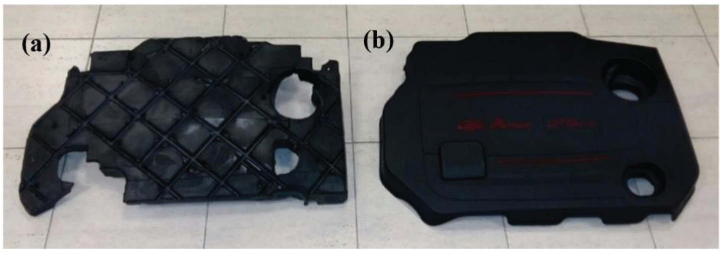


Fig. 2. Original cover configuration: (a) polyurethane foam (in contact with engine), (b) nylon skin (beauty cover).

The experimental test with and without the presence of cover allows to carry out the Insertion Loss parameter obtained from the difference between sound pressure levels in the prefixed position before and after the installation of the engine cover under the same conditions (ambient temperature and engine rpm speed). Fig. 3 reports radiated noise frequency spectra and corresponding Overall Level with and without cover presence for the single tested engine operating condition (@ 2000 rpm), relatively to the microphone located at a distance of 0.5 m from engine top face. As it is possible to observe, a lower effectiveness of the component in attenuating noise is visible in the low-medium frequency range (the plot area highlighted in light green), where a predominant noise emission occurs mainly to the first engine combustion frequency. In the high frequency range (plot area in Figure 3 highlighted in light blue), the radiated noise presents a region attenuated. Globally, the results show that only 1 dB of attenuation is seen when the engine is covered by the original cover. This result, obtained with the original configuration, leads to study the possibility of replacing the polyurethane material with other automotive ones.

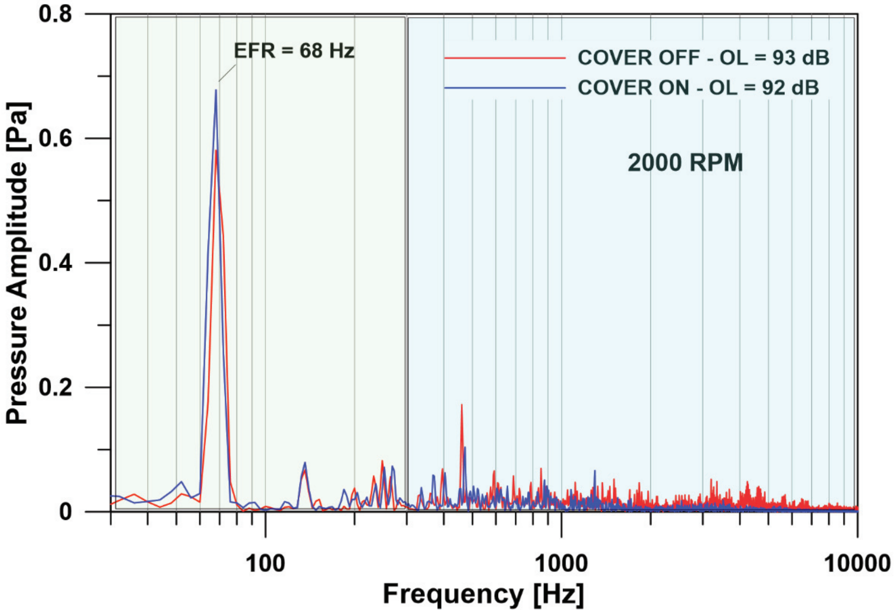
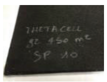


Fig. 3. Engine bay radiated noise vs. frequency with and without cover at 0.5 m of distance @ 2000 rpm.

For this reason, a second experimental test was carried out, by changing each time the sound-absorbing material originally applied under engine cover in nylon material and performing tests at the same engine operating conditions, in order to prove their capability in reducing noise. Some typical materials, commonly employed in automotive field, were initially selected and appropriately cut with the same original foam shape. In particular, Table 1 reports a list of the considered materials, where information about composition, density and thickness can be found.

Table 1. Properties of the employed materials.

TREATMENT		ID	SURFACE DENSITY [g/m^2]	THICKNESS [mm]
Basalt Wool		1	1500	5
Basalt Wool		2	1500	15
Thetacell		3	450	10
Thetafiber		4	1100	10
Polyester		5	600	40
Polyester		6	1200	5

Note that in the following each considered cover configuration will be appointed under the name of PA, which indicates the polyamide cover skin, followed by the identification number of each material listed in Table 1.

3. Results and discussion

For sake of brevity, only results related to microphone located at a distance of 0.5 m from engine top face for the 2000 rpm engine operating condition, are presented in the following. Fig. 4, in particular, reports for each cover configuration Overall Level (OL) expressed in decibel (dB).

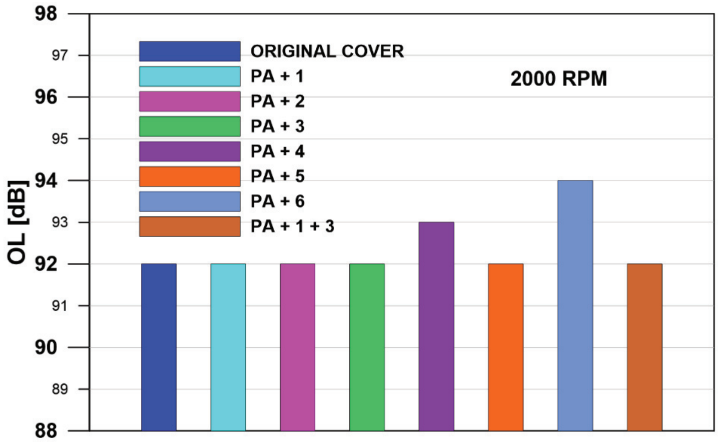


Fig. 4. Overall Level in dB measured for each cover configuration @ 2000 rpm.

By observing the bar plot, it is immediate to note that none of the new cover configurations seems to present a better noise attenuating behavior with respect to the original system. Some of the new tested solutions are even worse, producing an Overall Level increase of about 1-2 dB. However, it is important to specify that a mere analysis in terms of Overall Level would be reductive for a good comprehension of the results. For this reason acquired data have been also carefully analyzed in terms of acoustic pressure frequency spectra, allowing to highlight some not negligible occurrences. In fact, among all the new considered cover configurations only one material seems to ensure a better noise reduction with respect to the original cover in the frequency range higher than 300 Hz, despite a worsening at the low frequencies and especially at the Engine Firing Rate (EFR) is also seen. To give evidence of this, in Fig. 5 noise spectra @ 2000 rpm for the PA+5 and PA+1 solutions, are plotted and compared with the original cover one. As clearly evident in the zoom area in Fig. 5, PA+5 cover configuration shows pressure amplitude less pronounced than the other investigated solutions.

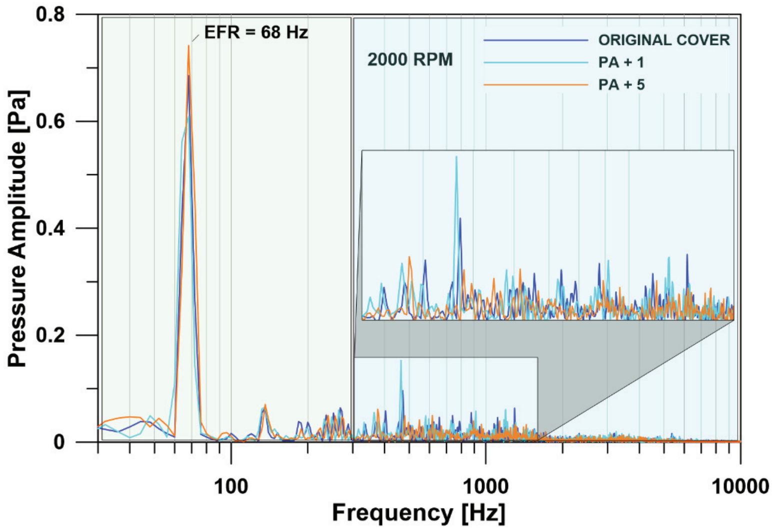


Fig. 5. Noise spectra comparison @ 2000 rpm between the original and two newly identified cover configurations.

In order to better understand the materials behavior in the investigated frequency range, an in-situ surface impedance method with pressure-velocity probe has been used. In the next paragraph a deep description of the employed method is presented.

3.1. PU based in situ absorption method

Current standard techniques for measuring the acoustic properties of materials are the well-known Kundt's tube (ISO 10534-2 and ASTM E1050-98) and the reverberant room method (ISO 354 and ASTM C423). These methods are often used for determining the acoustic absorption of small materials samples. On the other hand, several in situ measurement methods exist, but most of them are limited in frequency range, require large samples and can be affected by background noise or reflections [7].

In the present study, the most innovative PU in situ impedance method, has been used for investigating the acoustic properties of the different sound-absorbing materials listed in Table 1. The method is based on the measurement of sound pressure (P) and particle velocity (U) close to an acoustic absorbing material. A loudspeaker at a defined distance is used to generate a sound field with a known radiation impedance. It consists of measuring the impedance in situ close to the surface with a combined sound pressure and particle velocity sensor. From the impedance above the material also the surface impedance, reflection and absorption can be obtained.

Fig. 6 reports a schematized representation of the Microflown in situ absorption setup, with all the required instrumentation, consisting of the impedance gun with a spherical loudspeaker and an intensity PU mini probe, the MFDAQ-2 system acquisition and a laptop for post processing the results via Impedance software. The procedure is very simple: from the sound source, positioned 23 cm away from the PU probe, white noise or sine sweep signal is generated towards the measured sample. The sound pressure and acoustic particle velocity are measured right on the surface of the material [8]. The absorption and reflection coefficient can be obtained directly from the measured impedance, which represents the complex ratio of sound pressure and particle velocity. A fixed probe-source distance is also present for avoiding vibrations from the loudspeaker; in such way the probe is isolated from the sensor support. This is especially important when the impedance of the sample is high.

Measurement results are then properly processed through a dedicated software application, which provides a user friendly interface to visualize the measured acoustic properties, related to different material samples, as a function of frequency.

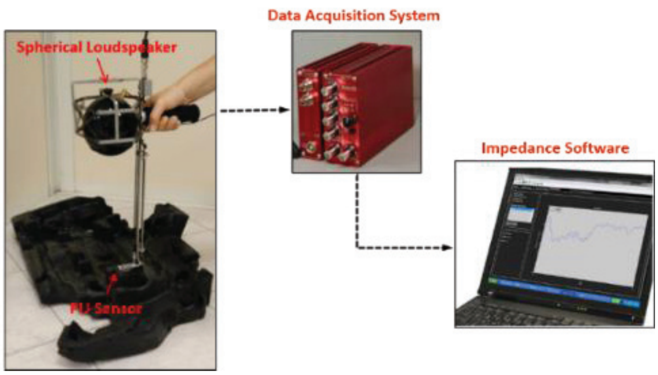


Fig. 6. In situ absorption setup.

Measurements were performed positioning the probe at a distance of about 5 mm from the sample, for avoiding effects due to background noise, reflections from other objects, and also because for larger probe-sample distances the sound reflected from the sample becomes weaker compared to the incoming sound.

According to the above described method, the absorption properties of the considered acoustic materials, were then determined. Obtained results are shown in Fig. 7 reporting the absorption coefficient of each investigated material as a function of frequency up to 5000 Hz. As it is possible to note from the graph, higher absorption values have been found for the Sample namely 5, particularly in the 300 Hz – 3000 Hz frequency range. Such result helps giving an explanation of the acoustic performance spectra shown in the previous paragraph for the PA+5 cover configuration above 300 Hz, with respect to the other tested solutions.

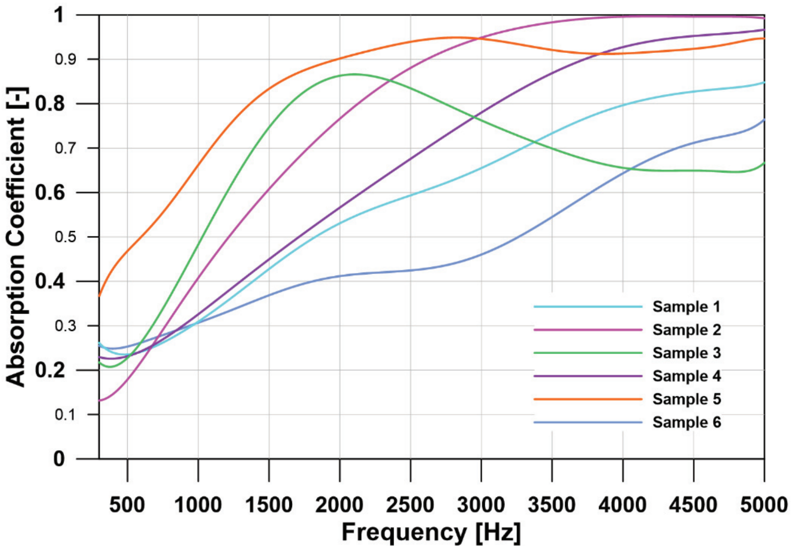


Fig. 7. Sound absorption as a function of frequency for the selected acoustic materials.

As a consequence, all acoustic data were then properly post-processed for comparing the different configurations in terms of Overall Level in the frequency range above 300 Hz. In the following the used methodology and obtained results are presented more in detail.

3.2. Acoustic data processing

In order to evaluate for each cover configuration the Overall Level contribution in the 300 Hz – 10000 Hz frequency range establishing a new OL comparison, a high-pass filter characterized by a cut-off value of 300 Hz has been implemented in LMS Test.Lab environment and applied to the acoustic signals in the time domain. New Overall Level (dB) values have been then calculated and plotted in Fig. 8 for each cover configuration.

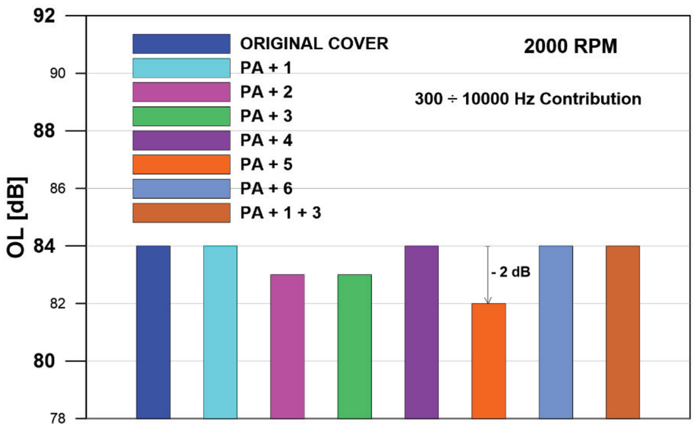


Fig. 8. Overall Level contribution in 300 Hz - 10000 Hz frequency range measured for each cover configuration @ 2000 rpm.

As expected, the PA+5 solution shows an overall noise reduction of 2 dB, the highest level reached among all others. This result leads to make some considerations about the possibility to consider the polyester material (ID 5, see Table 1) as a possible alternative to the already existing polyurethane foam. In particular some advantages could be found in using this material, such as a more lightweight and cost-effective solution with respect to the original foam. In addition, if properly treated, polyester could also ensure a proper fireproofing behavior.

In Fig. 9 the overall level is reported in the A-weighted overall level (dB(A)), it should be noted that only 1 dB(A) noise reduction is measured for the identified configuration at 2000 rpm engine operating condition. Since no substantial improvements have been found also at the other tested engine operating conditions, composite solutions should be taken into account in future configurations, identifying materials able to ensure good acoustic performance also at low frequencies.

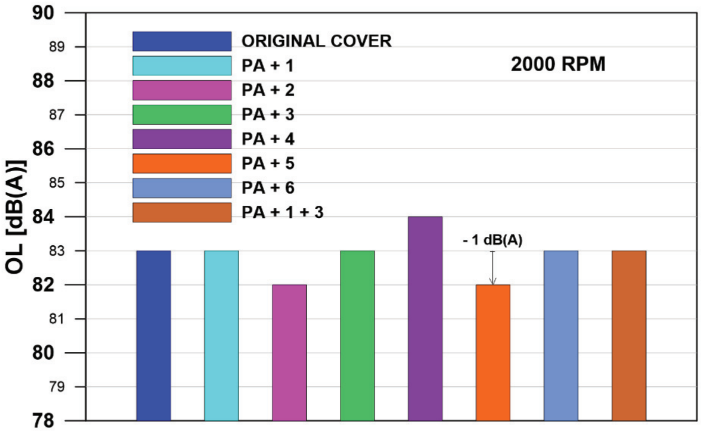


Fig. 9. A-weighted Overall Level measured for each cover configuration @ 2000 rpm.

4. Conclusion

In this work results coming from experimental analyses finalized to explore the use of different acoustical materials for reducing noise in a vehicle, have been presented. More in detail, different engine cover solutions were investigated by substituting the original polyurethane material with different materials employed in automotive. These new configurations were subsequently tested in real engine operating conditions, by measuring engine radiated noise through the use of typical pressure microphones for far field measurements, in accordance with the prescribed standards. The results were presented in terms of Overall Levels (dB) frequency spectra. In order to better understand the acoustic behavior of the employed materials, an innovative in situ impedance measurement by using PU sensor, has been also exploited. The results have shown that by applying a high pass filter for acoustic data in the time domain, a possible solution ensuring a better noise reduction behavior at mid and high frequencies, with respect to the original one, should be utilized. This new engine cover configuration could also represent a less expensive and more lightweight solution. However, as a slight improvement of the A-Weighted Overall Level was found for this particular configuration over all frequency range of interest, further analyses should be performed, in order to identify composite solutions composed by materials able to enhance noise reduction performance also in the low frequencies. Further experimental investigations are now being pursued intensively.

References

[1] Saha, P. Developing Vehicle Sound Packages. *Sound & Vibration*, 2011, 45.10: 10-14.
[2] Beigmoradi, S.; Jahani, K.; Hajabdollahi, H. Investigating the transmission loss effect via optimizing the insulator package on vehicle's firewall. In: *Proceedings of Meetings on Acoustics*. *Acoustical Society of America*, 2013. p. 065007.
[3] Siano, D. , Viscardi, M., Aiello, R., Experimental and numerical validation of an automotive subsystem through the employment of FEM/BEM approaches , Energy Procedia, Volume 82, Pages 67-74, 70th Conference of the Italian Thermal Machines Engineering Association, ATI 2015, ISSN: 18766102, DOI: 10.1016/j.egypro.2015.11.884.
[4] Siano, D.; Viscardi, M.; Panza, M. A. Experimental Acoustic Measurements in Far Field and Near Field Conditions: Characterization of a Beauty Engine Cover. *Recent Advances in Fluid Mechanics and Thermal Engineering*, 50-57.
[5] Siano, D., Viscardi, M., Aiello, R., Sensitivity analysis and correlation Experimental/Numerical FEMBEM for Noise Reduction assessment of an engine beauty cover, Energy Procedia Volume 81, 1 December 2015, Pages 742-754, ISSN: 18766102, DOI: 10.1016/j.egypro.2015.12.080.
[6] ISO 3744:2010. Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane.
[7] Tijs, Emiel, and Erik Druyvesteyn. An intensity method for measuring absorption properties in situ. *Acta Acustica united with Acustica* 98.2 (2012): 342-353.
[8] Microflown Technologies Ebook, *Near Field Acoustics*.