

Experimental Acoustic Measurements in Far Field and Near Field Conditions: Characterization of a Beauty Engine Cover

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Abstract: - Present work focuses on experimental acoustic characterization of an engine beauty cover in far field and near field conditions. Specifically, a comparison between results coming from the two different experimental measurement techniques is presented. Experimental campaign has been carried out on a car engine compartment at different operating conditions, by using on one hand a typical pressure microphone for far field measurements accordingly the related prescribed standards, and on the other hand the more innovative Microflow $p-u$ intensity probe (pressure – particle velocity sensor) for near field measurements. In the latter case, experimental tests have been conducted adopting the Scan & Paint method, based on the acquisition of sound pressure and particle velocity by manually moving the probe across the sound field whilst filming the event with a camera. Differently obtained results have been then analyzed highlighting the peculiarities of each of the two techniques. Finally, evaluating noise emissions with and without cover presence, it has been possible to verify the acoustic performances of the component, identifying a less performing acoustic behavior of the material at some specific frequencies. Hence, future developments could regard the possibility to implement an optimization process through the analysis of different materials and configurations, in order to improve cover acoustic insulation properties at the frequencies of interests.

Key-Words: - Acoustic Measurements , Sound Intensity, Engine Cover, Acoustic Performances, Scan & Paint Technique

1 Introduction

In the last years, all the big automotive manufacturers have directed great interest on NVH characteristics of vehicles. The problem of noise and vibration reduction could regard several components and modules of the automotive, such as panels, doors, engine covers, seats, and others. Of course, engine noise represent the most relevant component of the overall noise perceived inside a car; it mainly derives from the rapid pressure increase that occurs in the cylinder as a result of the combustion process. The engine cover, in addition to represent an aesthetic component on engine's top, if well-designed could be able to reduce noise emissions producing a better acoustic comfort of the cabin. For these reasons the study of innovative materials, which ensures the required noise abatement in all the circumstances, is nowadays a very important research topic.

Improvements of the acoustic comfort can be reached only starting from an accurate evaluation of vehicle noises. Standardized exterior and interior noise tests are commonly used to determine the sound quality of vehicles in development. The combination of static tests and on-road measurements is essential to undertaking a successful refinement process.

The sound power value is certainly an important parameter for noise emission of products. It is used for compliance and benchmarking in a lot of market, also in automotive field.

Typically, the unique descriptor of the noisiness of a sound source is the sound power, a quantity more or less independent of the environment. Common acoustic measurements are carried out to state how much noise is being radiated and by what machine. In several applications it is important to know the sound power of the individual sources and to rank them in order of highest sound power. Once located the source making most noise, it could be necessary to reduce the noise by locating the individual components radiating sound. Previously it was possible measure only pressure, which is dependent on the sound field. Sound power can be related to sound pressure only under carefully controlled conditions where special assumptions are made about the sound field. Specially constructed rooms such as anechoic or reverberant chambers fulfil these requirements. However, the majority of sound measurements are made in rooms that are neither anechoic nor reverberant – but somewhere in-between [1]. This makes it difficult to find the correct measuring positions when the noise emission from a

given source must be measured. If measurements are made by using a pressure microphone positioned too close to the sound source, the SPL (Sound Pressure Level) may vary significantly with a small change in sensor position. This will occur at a distance less than the wavelength of the lowest frequency emitted from the source. This area is termed the near-field of the sound source, and measurements in this region should be avoided if possible. Other errors may arise if the measure is made too far away from the source. Here, reflection from walls and other objects may be just as strong as the direct sound from the emitting source and correct measurements is not possible. This region is termed the reverberant-field. Between the reverberant and near-field is the free-field which can be found by noting that the level drops 6 dB for each doubling in distance from the source. SPL measurements should be made in this region. However, it is quite possible that the conditions are so reverberant or the room is so small that no free-field exists. In such cases some standards (such as ISO 3746) suggest an environmental correction to account for the effect of reflected sound.

It should be noted that, thanks to the development of more modern measurement techniques, investigations in situ can be now performed obtaining the sound power emitted by a source directly from acoustic intensity, the measure of which doesn't require the presence of specific sound fields. As acoustic intensity gives, in addition, information about sound propagating direction, it can be considered a very useful tool for defining sound sources localization.

In this paper two different measurement techniques, finalized to the acoustic characterization of an engine beauty cover, are presented.

The flux diagram showed in Fig. 1 allows to better understand the main steps realized and what were aimed to.

Experimental data have been acquired on an engine compartment, with and without cover presence and at different stationary operating condition in terms of reached engine speed.

The first technique, in far field conditions, makes use of a pressure microphone positioned at a fixed distance from the engine. This type of measurement could be carried out as the car was placed in such a large room that the presence of free field conditions could be assumed.

The second technique relies on the use of the Microflwn $p-u$ intensity probe (pressure – particle velocity sensor), suitable for near field measurements. Specifically, a novel sound field mapping procedure, named Scan & Paint [2], has been utilized. The technique is based on the

acquisition of sound pressure and particle velocity by manually moving a $p-u$ probe across the sound field, while a camera films the event. The sensor position is extracted by applying automatic color tracking to each frame of the recorded video. It is then possible to directly visualize sound variations across the space in terms of sound pressure, particle velocity or acoustic intensity.

Results coming from both adopted methodologies have been then analyzed and compared in detail.

Having available radiated noise levels with and without cover presence, acoustic performances of the engine cover have been easily analyzed, evaluating its acoustic attenuation properties in the frequency domain. As a worse acoustic behavior has been identified at some specific frequencies, future research activities will be conducted through the implementation of numerical simulations in order to realize an acoustic optimization process of the component [3] [4] [5].

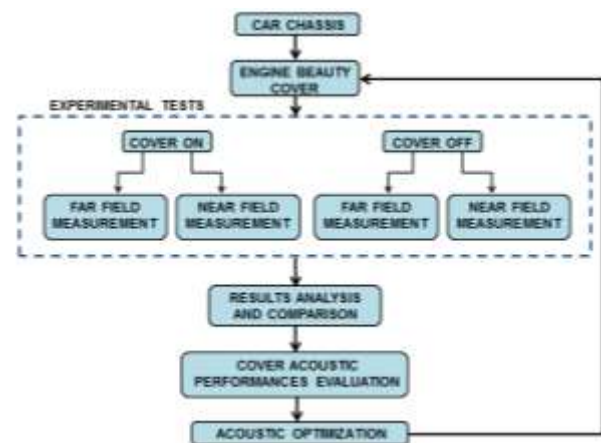


Fig.1: WBS diagram of the implemented procedure

2 Far Field Sound Measurements

The far field of a source begins where the near field ends and extends to infinity. Note that the transition from near to far field is gradual in the transition region. In the far field, the direct field radiated by most sources will decay at the rate of 6 dB each time the distance from the source is doubled.

As long as the source to sensor distance is more than a few times the maximum acoustic wavelength and the sensor's dimensions are small compared with the minimum wavelength, the waveform arriving at each sensor is essentially planar and the source is considered in the far field [6].

For present work's aims far field measurements of engine radiated sound have been performed by using a pressure microphone, properly located as shown below. The use of this type of transducer was possible

for the particular conditions in which test has been carried out, as a very large room could reproduce the free field conditions.

Pressure microphones are the most common devices used to measure sound pressure [2]. They have an internal membrane which responds to pressure fluctuations in air in the same way as human eardrum, moving backwards and forwards as the pressure force acts over the membrane surface. The motion of the membrane is converted into an electric signal by a transducing element.

A sound pressure microphone is omni-directional and thus measures the sound field in all directions, that is the total sound field.

2.1 Experimental Setup

Experimental tests to determine engine acoustic emissions have been executed in order to know their influence on vehicle interior sound quality, specifically on the driver's acoustic comfort. In Fig. 2, which shows a schematic representation of test setup, it is then possible to distinguish an external pressure microphone (indicated as M1) for measuring engine noise level, and two internal pressure transducers (indicated as M2 and M3) placed on the driver seat close to his head. M1 microphone was placed according to geometric data reported in Fig. 2. An accelerometer located at one engine-chassis joint position is also visible (ACC); its main scope is to measure the chassis structural contribution to the overall radiated noise [7] [8], in order to isolate engine noise which is mainly due, as known, to the internal combustion process.

More in detail, the necessary equipment used for acquiring experimental data (Fig. 2) was composed by:

1. three pressure transducers (Microflown Class 1 ICP microphones);
2. a PCB tri-axial accelerometer;
3. a multi-channel FFT analyzer (Scadas III Acquisition System);
4. a pre and post-processing software (LMS Test.Lab).

For sake of brevity in the following only results related to M1 pressure microphone will be presented, as the main task of present work is the acoustic characterization of the engine cover.

Data have been acquired, with and without cover presence, at three different engine operating conditions:

1. 800 rpm (idle condition);
2. 1500 rpm;

3. 2000 rpm.

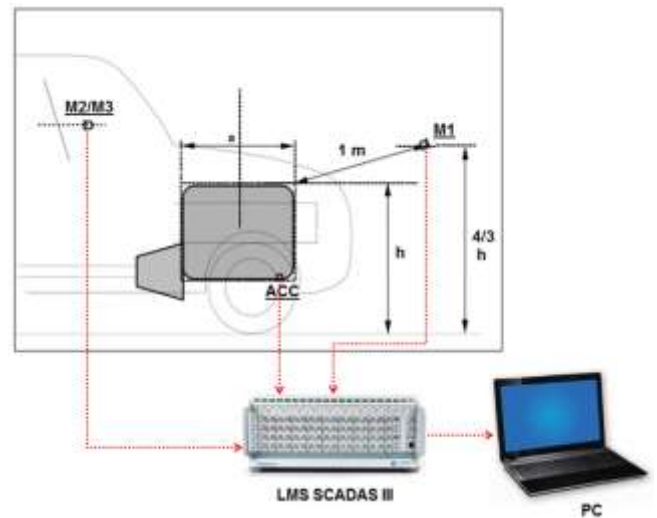


Fig. 2: Experimental setup of far field measurements

2.2 Far Field Results

In Figs. 3-4 are reported Sound Pressure Level values as a function of frequency expressed in one third octave bands. Bar graphs refer to idle and 2000 rpm conditions, with and without cover presence.

It is possible to observe that the increase of engine speed, in addition to produce higher noise levels, lead to a shift of the SPL peak towards the higher frequencies. This is related to the combustion frequencies which grow up with increasing engine speed.

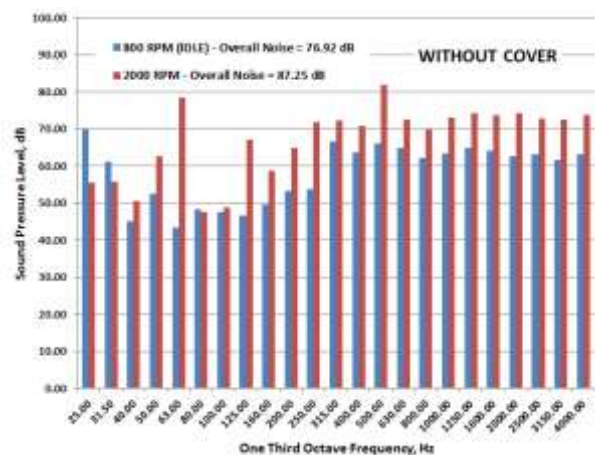


Fig. 3: Sound Pressure Level as a function of frequency without cover presence at 800 and 2000 rpm

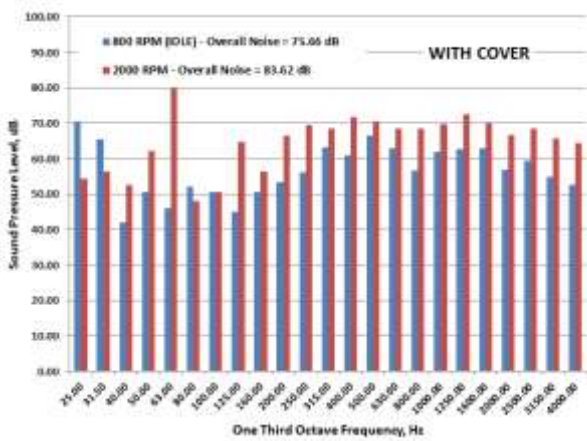


Fig. 4: Sound Pressure Level as a function of frequency with cover presence at 800 and 2000 rpm

3 Near Field Sound Measurements

As long as the source to sensor distance is in the order of acoustic wavelength, the source is considered in the near field [9].

Most of the methods for reconstructing sound pressure, particle velocity and sound intensity on a surface out of a near field measurement are scientific proven in an anechoic environment and under favorable conditions. The problem is that in most practical situations background noise influences the results considerably.

On the contrary, the ‘direct method’, that is simply measuring the sound pressure and particle velocity close to the surface, can be used in diffuse sound fields and with correlated and non-correlated sound sources. So real life measurements in a car, just as source finding on an engine, are very well possible. From the measure of particle velocity and sound pressure close to the source the sound intensity can be derived quantifying directly the amount of sound that the sources emit.

3.1 Pressure-Velocity Sound Intensity Probe

The Microflown p - u probe is the combination of a pressure microphone and a particle velocity transducer. It directly measures the scalar value ‘sound pressure’ and the vector value ‘acoustic particle velocity’ in one spot, giving the sound intensity.

The velocity sensor is a miniaturized device based on two tiny platinum wires (Fig. 5), which are kept constantly heated to 200 degrees. The motion of the air surrounding them produce a temperature decrease in the first wire, the second wire is then less cooled down by the flow. This temperature difference is

proportional to the wires resistance, providing a broad band (0 to at least 10 KHz) and linear signal proportional to the particle velocity.

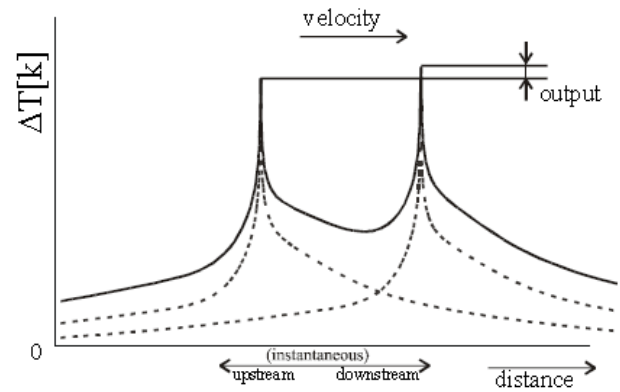
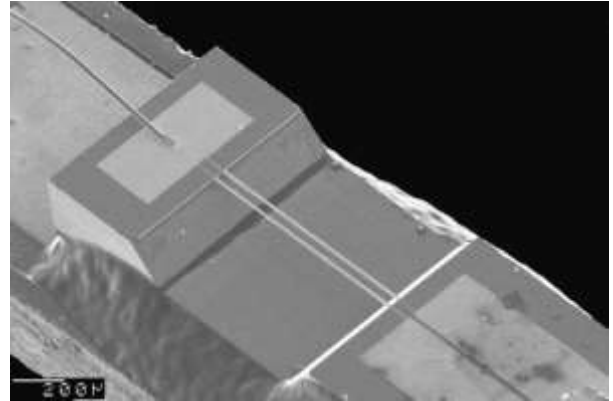


Fig. 5: Operation principle of the Microflown sensor

The sound intensity in a generic direction r is simply the time average of the instantaneous product of the pressure and particle velocity signal [10],

$$I_r = \langle p \cdot u_r \rangle_t = \frac{1}{2} \text{Re} \{ p \cdot u_r^* \}$$

where p is sound pressure, u_r is particle velocity in r -direction and $\langle \cdot \rangle_t$ indicates time averaging.

Before particle velocity sensors became available, a finite difference approximation of the pressure gradient using two phase matched pressure transducers (the so called p - p method) estimated the particle velocity signal [11] [12]. Due to the near field benefits using the direct measure of the directional particle velocity, p - u probes are not highly affected by background noise or reflections and measurements can be undertaken in real operational situation even in cases with a high sound pressure over sound intensity ratio. Microflown p - u probes are very small facilitating the ease of use significantly. The small sensor size makes it possible to have an unparalleled spatial resolutions compared to any

other method. The bandwidth is very large. In theory it can be from frequencies far below 20Hz and above 20kHz. At the lower end however the measurement error increases for intensity measurements due to that the relative distance (the measurement distance compared to the wave length) decreases and therefore the reactivity of the sources increases. The measurement error is decreased by enlarging the measurement distance.

Microflow p - u probe measurements on the engine compartment have been performed adopting the Scan & Paint technique [2]. The method is very simple (Fig. 6); the acoustic signals of the sound field are acquired by manually scanning the emitting surface with a single p - u probe while a camera is positioned toward the surface to film the scanning. In the post-processing stage, the sensor position is extracted by applying automatic color detection to each video frame. It is then possible to split the long recording into multiple segments by applying a spatial discretization algorithm. Each fragment of the signal is linked to position depending upon the location of the probe during the measurement. Spectral variations across the measurement area are computed by analyzing the signal segments of each grid section. A link between the 2D coordinates of the image space and the 3D coordinates of the measurement scenario is later established by defining the correspondence between pixels and meters. A high resolution sound color map is produced as result.



Fig. 6: Basic steps of the Scan & Paint measurement method

3.2 Experimental Setup

Fig. 7 shows the experimental setup with the appropriate instrumentation required for measurements, consisting of the intensity p - u mini probe, a laptop equipped with Scan & Paint software, MFDAQ-2 system acquisition, and a web camera.

The main objective has been, as in the far field case, the measure of sound radiated from the engine at different stationary operating condition, with and without cover presence.

The scanning has been carried out at the distance of approximately 2 cm from the surface of the noise source (the internal combustion engine). A colored label has been used for camera detection of probe path.



Fig. 7: Experimental setup of near field measurements

3.3 Near Field Results

Acquired data have been then processed in terms of frequency spectrum of the particle velocity signal (PVL-Power Velocity Level). In Fig. 8 is reported the measured PVL at idle condition and without cover on engine top. Note that that the first four peaks of PVL in Fig. 8 correspond to engine combustion frequencies at 800 rpm, as expected for a four-cylinder engine.

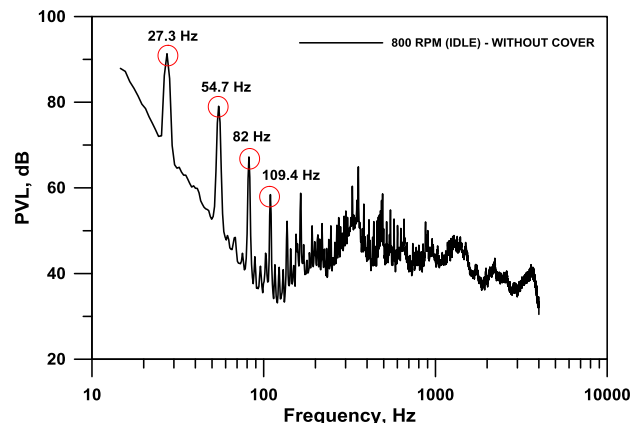


Fig. 8: Power Velocity Level as a function of frequency at 800 rpm without cover presence

In Fig. 9 is shown the acoustic map of particle velocity at the frequency of 27.3 Hz.

It is immediate to note that the main acoustic emissions come from the internal combustion engine, which radiates up to 95 dB.

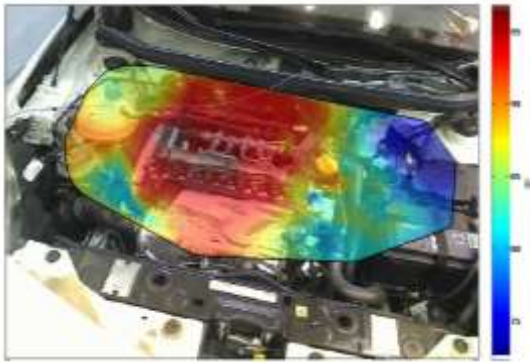


Fig. 9: Acoustic map of particle velocity at 27.3 Hz (800 rpm without cover presence)

In the following pictures and graphs, results related to the other tested conditions are reported too.

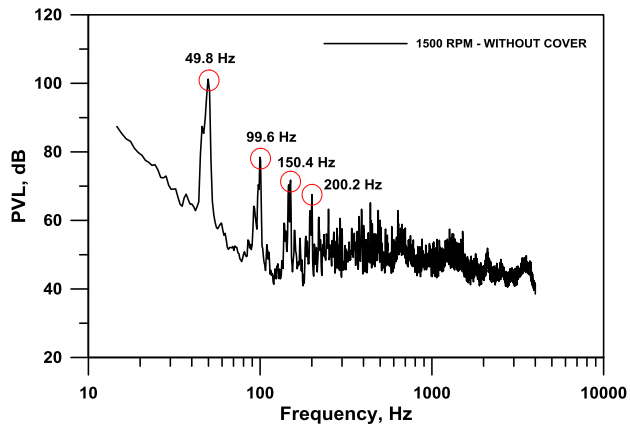


Fig. 10: Power Velocity Level as a function of frequency at 1500 rpm without cover presence



Fig. 11: Acoustic map of particle velocity at 49.8 Hz (1500 rpm without cover presence)

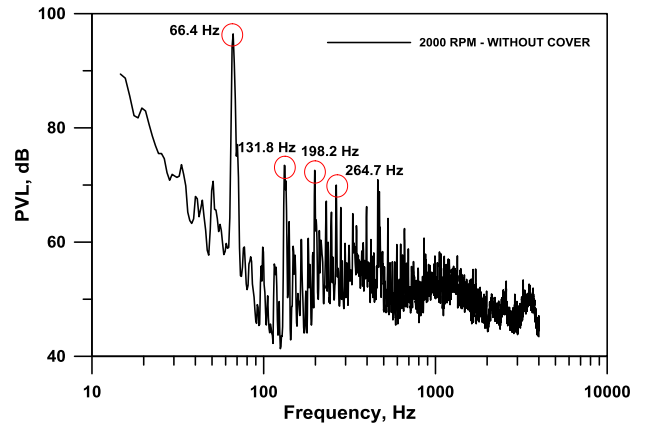


Fig. 12: Power Velocity Level as a function of frequency at 2000 rpm without cover presence

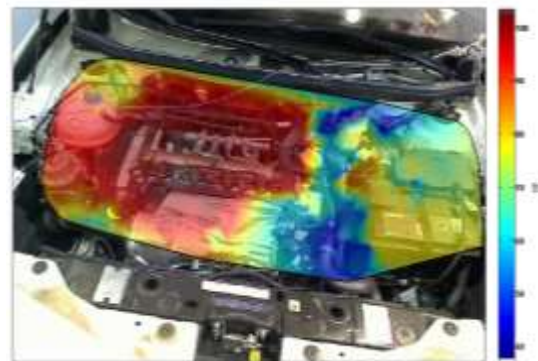


Fig. 13: Acoustic map of particle velocity at 66.4 Hz (2000 rpm without cover presence)

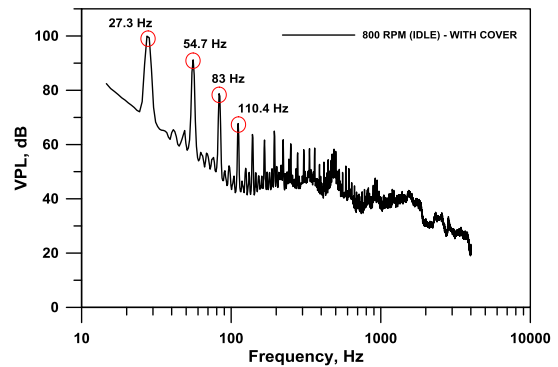


Fig. 14: Power Velocity Level as a function of frequency at 800 rpm with cover presence

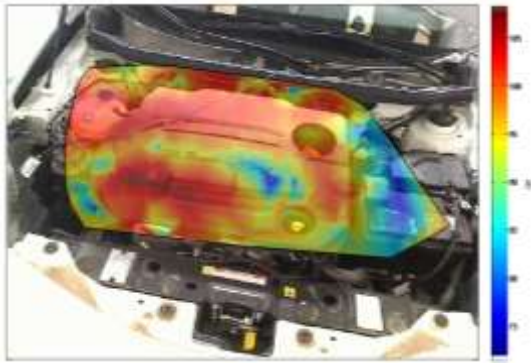


Fig. 15: Acoustic map of particle velocity at 27.3 Hz (800 rpm with cover presence)

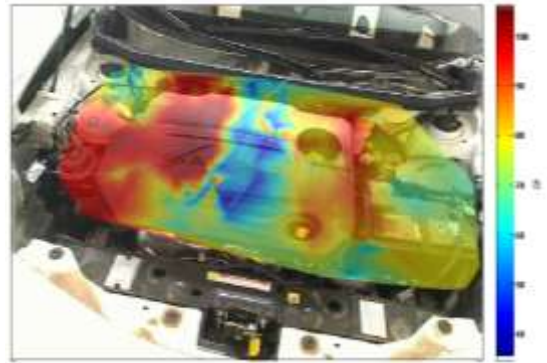


Fig. 19: Acoustic map of particle velocity at 66.4 Hz (2000 rpm with cover presence)

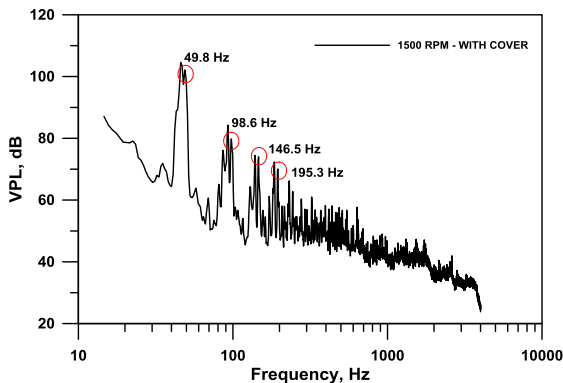


Fig. 16: Power Velocity Level as a function of frequency at 1500 rpm with cover presence



Fig. 17: Acoustic map of particle velocity at 49.8 Hz (1500 rpm with cover presence)

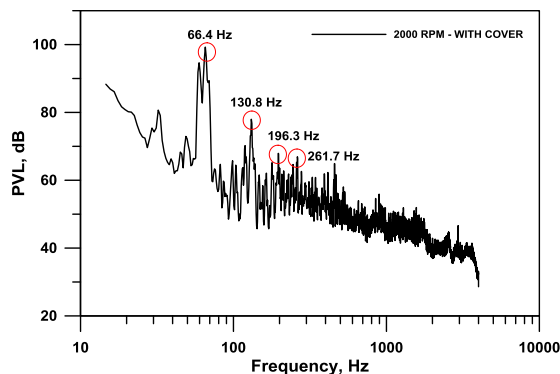


Fig. 18: Power Velocity Level as a function of frequency at 2000 rpm with cover presence

4 Result's synthesis and Conclusion

In this work results coming from experimental analyses finalized to the acoustic characterization of an engine beauty cover have been presented. Specifically, performed tests, executed on engine compartment at three stationary operating conditions, regarded two different measurement techniques.

Far field measurements have been realized by the use of a typical pressure transducer located at appropriate distance from the engine, whereas near field measures have been carried out through the more innovative *p-u* sound intensity probe adopting the Scan & Paint method.

Near fields velocities have been then processed to compute the related sound field at the target point. Relative data have been compared in the next tables 1 and 2.

OVERALL NOISE WITHOUT COVER		
	FAR FIELD	Extrapolated from NEAR FIELD
800 RPM (IDLE)	76.9 dB	77.8 dB
1500 RPM	84.2 dB	83.7 dB
2000 RPM	87.3 dB	85.4 dB

Table 1: Measured and provisional sound pressure level without beauty engine cover

OVERALL NOISE WITH COVER		
	FAR FIELD	Extrapolated from NEAR FIELD
800 RPM (IDLE)	75.7 dB	78.3 dB
1500 RPM	81.9 dB	84 dB
2000 RPM	83.6 dB	84.1 dB

Table 2: Measured and provisional sound pressure level with beauty engine cover

Data comparison show on one side the good agreement of far fields measured data and provisional one based upon the near field computation.

As other result, the effectiveness of engine beauty cover as a noise limitation object, has been evaluated at different engine working condition.

These data will be used as reference data for successive numerical simulations and optimization processes.

References

- [1] Brüel & Kjær Measuring Sound Guide.
- [2] Daniel Fernandez Comesana, *Scan-Based Sound Visualisation Methods using Sound Pressure and Particle Velocity*, Thesis for the degree of Doctor of Philosophy, University of Southampton – Institute of Sound and Vibration Research, July 2014.
- [3] Siano D., Amoroso F. , *FEM/BEM numerical modeling of a diesel engine acoustic emission*, In: 19th International Congress on Acoustics - ICA 2007, International Commission for Acoustics, ISBN: 84-87985-12-2, Madrid.
- [4] E. Armentani , R. Trapani, R. Citarella , A. Parente, M. Pirelli, *FEM-BEM Numerical Procedure for Insertion Loss Assessment of an Engine Beauty Cover* , The Open Mechanical Engineering Journal, 2013, 7, 27-34 27.
- [5] K.A. Cunefare, G. Koopmann, and K. Brod, *A boundary element method for acoustic radiation valid for all wavenumbers*, Journal of the Acoustical Society of America, 85(1):39–48, 1989.
- [6] Microflown Technologies Ebook, *Far Field Acoustics*.
- [7] R. Citarella, P. Colantuono, and D. Siano, *Vibration prediction of a multi-cylinder engine using multi-body dynamic simulation*, In: 41^o National Conference AIAS 2012, Vicenza, Italy, September 5-8, 2012.
- [8] D. Siano, *Engine Noise Prediction by Using Multi-body Simulation*, Journal of Environmental Science and Engineering B1, ISSN: 1934-8932, pp. 1146-1161, 2012.
- [9] Microflown Technologies Ebook, *Near Field Acoustics*.
- [10] Microflown Technologies Ebook, *Intensity*.
- [11] Daniel Fernandez Comesana, Jelmer Wind, Andrea Grosso, Keith Holland, *Performance of p-p and p-u intensity probes using Scan & Paint*, 18th International Congress on Sound & Vibration ICSV18, Rio De Janeiro, Brazil, July 2011.
- [12] D. Siano, M. Viscardi, P. Napolitano, M. A. Panza, *Numerical and Experimental Acoustic Performance Investigations of a High-Speed Train Composite Sandwich Panel*, WSEAS TRANSACTIONS on APPLIED and THEORETICAL MECHANICS, E-ISSN: 2224-3429, Volume 9, pp. 290-300, 2014.
- [13] Corcione, F.E. , Siano, D. , Iadevaia, M. , Viscardi, M. , Corcione, G.E. , Lavorgna, M.” *Correlation between the acoustic intensity measurements with and without an electronically fuel injection system for a small single cylinder diesel engine”* (2003) *Acta Acustica (Stuttgart)*, 89 (SUPP.), pp. S33 - ISSN: 16101928 CODEN: AAACF
- [14] Corcione F.E. , Siano D. , Vaglieco B.M , Corcione G.E. , Lavorgna M. , Viscardi M. , Iadevaia M. , Lecce L. “*Analysis and control of noise emissions of a small single cylinder D.I. diesel engine”* (2003) SAE Technical Papers, DOI: 10.4271/2003-01-1459