45º CONGRESO ESPAÑOL DE ACÚSTICA
8º CONGRESO IBÉRICO DE ACÚSTICA
EUROPEAN SYMPOSIUM ON SMART CITIES AND ENVIRONMENTAL ACOUSTICS

AN APPLICATION OF OPERATIONAL PATH ANALYSIS (OPA) ON AN ELECTRIC CAR

PACS Nº 43.50.Yw

Cervantes-Madrid, Gines(1); Palenzuela-Andújar, Juani(1); Diez-Ibarbia, Alberto(2); Mattia Battarra(3); Theodossiades Stephanos(4); Walsh, Stephen(4); Peral-Orts, Ramon(1); Campillo-Davo, Nuria(1)

1. Universidad of Miguel Hernández
Av. Universidad s/n, 03202, Elche. Spain
2. Universidad of Cantabria
Avda. de Los Castros s/n, 39005, Santander. Spain
3. Università degli Studi di Ferrara
Via Savonarola, 9, 44121 Ferrara, Italy
4. Loughborough University
Epinal Way, Loughborough LE11 3TU, UK

ABSTRACT

In the last 30 years, automotive companies have shown keen interest in improving the vibrational and acoustic behaviour of their vehicles and several methods have been developed in order to solve vehicle NVH problems. Nowadays, these methodologies are used to study the behaviour of Electric Vehicles (EV) and improve mechanical aspects related with NVH.

Within this framework, the envisaged mission for this work is to carry out a procedure in order to obtain and assess the transfer path in the passive elements of electrical vehicles.

The work presented in this paper reflects the realization of an Operational Path Analysis (OPA). There are several reasons for choosing this approach, mainly its speed of execution and simplicity.

RESUMEN

En los últimos 30 años, los fabricantes de automóviles han mostrado un gran interés en mejorar el comportamiento vibratorio y acústico de sus vehículos y se han desarrollado varios métodos con el fin de resolver los problemas de ruido y vibraciones (Noise, vibration, and hardness) en los mismos. En la actualidad, estos métodos están siendo aplicados para el estudio del comportamiento sonoro y vibratorio de los vehículos eléctricos (EV).

Dentro de este marco, la misión prevista para este trabajo es llevar a cabo un procedimiento con el fin de obtener y evaluar los caminos de transferencia de ruido en los elementos pasivos de los vehículos eléctricos.

El trabajo presentado en este documento refleja la realización de una Operational Path Analysis (OPA). Hay varias razones para elegir este método, sobre todo su velocidad de ejecución y simplicidad.

INTRODUCTION

Recently, automotive companies are increasingly showing interest in improving the vibrational and acoustic behaviour of their vehicles and several methods have been developed in order to solve vehicle NVH problems [3].

With regards to this issue, the vehicle system can be classified within three different elements depending on their behaviour: 1) sources: the elements that create/generate vibrations or noise, 2) receivers: the elements that receive the fluctuations and 3) passive paths: the ways that the oscillations are propagating themselves [1].

Within this framework, the mission for this stay is to carry out a procedure in order to obtain and assess the transfer path in the passive elements of electrical vehicles. The transfer path analysis is an approach used to analyse the effects that the different vibrational or acoustical sources produce on the points of interest. In this study, structure-borne sources such as the engine and suspensions have been assessed measuring the influence of these sources on the cabin and specifically on driver's ear.

From the literature, several approaches to obtain the transfer path analysis have been studied [6]; one of those being the OPA, which is this study's chosen approach. There are several reasons for choosing this approach, namely because it is the most significant with regards to speed (the fastest approach) and additionally due to its simplified complexity.

METHOD

The Operational Path Analysis (OPA) can be divided in three main stages: Operational measurements, Transmissibility function calculation and Results and assessment.

For the operational measurements, a run-up test is performed at a range of frequencies of interest. This way the excitation is introduced to the system while the motion and the acoustic pressure are measured.

With the acceleration and acoustic pressure measurements, the transmissibility functions are calculated using equation (1).

$$p_r(\omega) = \sum T_i(\omega) \cdot a_i(\omega) \tag{1}$$

Once the transmissibility functions have been calculated, they can be used with other measurements for different run-up tests.

Hence, the acoustic pressure can be calculated and can be compared with that measured in the actual measurement.

Finally, the collated results are assessed thus determining which transfer path is the most critical one for each specific frequency.

OPERATIONAL MEASUREMENTS

To develop the logistics of the tests, it was necessary to define the number of measurement points, as well as their location in the vehicle, depending on the OPA requirements.

Before choosing the measurement points located on the main paths of noise and vibration transfer, it was necessary to analyse the disposition of the mechanical elements in the car on which it will work.

The car is a small fully electric car. A basic scheme of the main components can be seen in Figure 1. The powertrain is over the rear axis in this configuration.

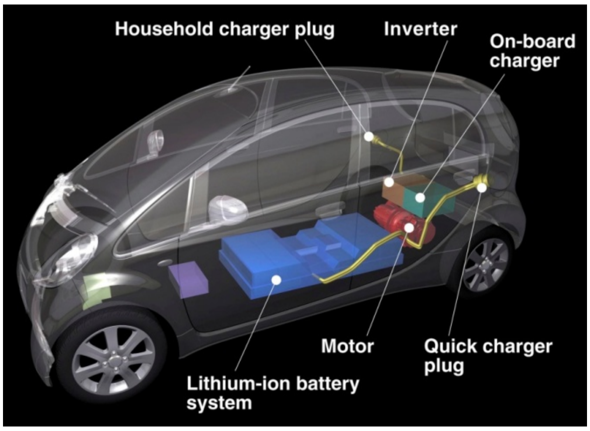


Figure 1: Main components layout [2]

Five points were chosen, the first three correspond to the three main powertrain mounts. In each of them, measurements of the vertical and longitudinal axes of the vehicle were taken (Figure 2).

Furthermore, two measuring points were established at the locations where the rear suspension is supported because through these supports, rolling noise and vibration are also introduced.

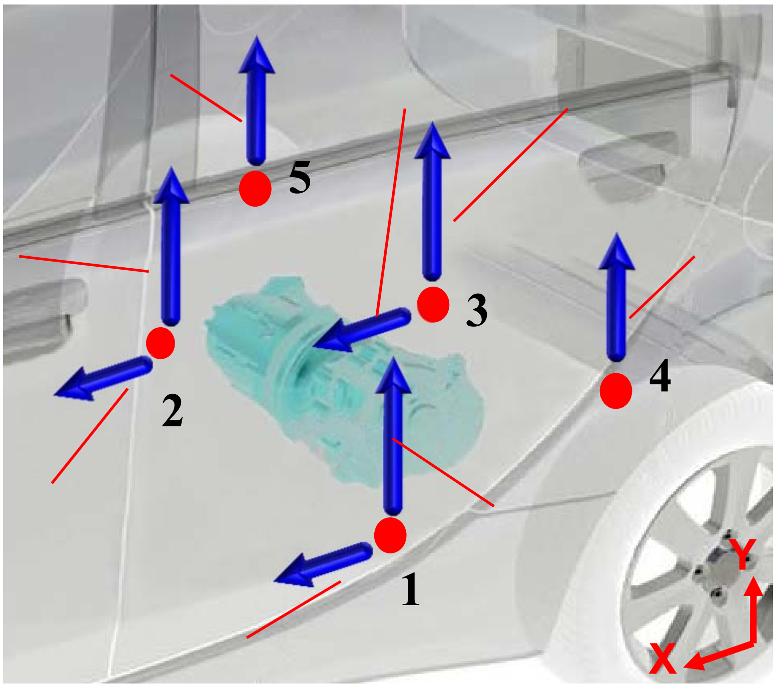


Figure 2: Accelerometers installed in their position

The microphone inside the car was positioned in the same location as the driver's ear.

The next step was to develop a preliminary application in LabVIEW to record the acquired data directly as they have been acquired to allow further processing.

After defining the logistic process, the electric vehicle was installed in the roller bench to initiate the tests. Many tests were completed to have enough measurements for the post process part.

The application then produced a data file so that the values of the acquired signals are registered exactly as they have been acquired.

To facilitate the post-processing in Matlab, instead of working with the data as they are accumulated, another application was developed in LabVIEW to allow the channels to be ordered appropriately and also to convert all the data into more convenient units.

In this file, the accelerations are given in m/s^2, the acoustic pressure is sent to two separate channels (Pa and dBA) and the vehicle speed is expressed in km/h.

The aim now will be to define the transmissibility matrix.

TRANSMISSIBILITY FUNCTION

For operational measurements, particularly in NVH analysis of vehicles, the response is often related to the receiver at several operational states, that is the case of the RPM of the engine.

In this case, the input and output measurement data are constantly changing. However the reference (input) and response (output) are always related by the corresponding transfer function.

Assuming that the relationship between reference (input) and response (output) are linear and constant for each measurement block and performing the computation for each frequency component, that is to say for each line of the discrete Fourier transform (DFT) of the sampled reference and response measurement. The main equation of the OPA (1) can be defined in compact form (2) [3, 4].

$$P_r = T \cdot A \tag{2}$$

Therefore the next step is to calculate the transmissibility matrix. The measurements are introduced into the OPA main equation following the process described above and then the different elements of the matrix "T" are calculated using the H1 estimator method.

After having obtained the transmissibility matrix, it is necessary to change the data file before calculating results. This way, the validity of the method is tested using the experimental matrix to obtain the acoustic pressure of a completely different test.

RESULTS AND ASSESSMENT

To establish the results, acceleration data were used from new measurements and were multiplied for the transmissibility matrix previously calculated.

The acoustic pressure can be calculated using the measured acceleration and the experimental transmissibility of the system and after it can be compared with other experimental acoustic pressure in order to evaluate the efficiency of the method.

Once the results have been obtained, they can be compared to both acoustic pressure signals. Consequently, the results are significant as they collaborate effectively. This means that the mathematical process used is able to calculate quite accurately the actual acoustic pressure.

Figure 3 presented the spectral maps of the eight different paths whose amplitude indicates the contribution in dB of each one to the total acoustic pressure. It provides a clear example of a common basis of paths behaviour. However each of the paths has a different behaviour at different frequencies, filtering or emphasizing the sound transmitted to the passenger compartment. When the sound pressures of the eight paths are summed, the Calculated Acoustic Pressure is obtained. The comparison of the two Acoustic Pressure signals, calculated and measured, can be seen in Figure 4, in which the spectral maps of both signals from above and in perspective are presented.

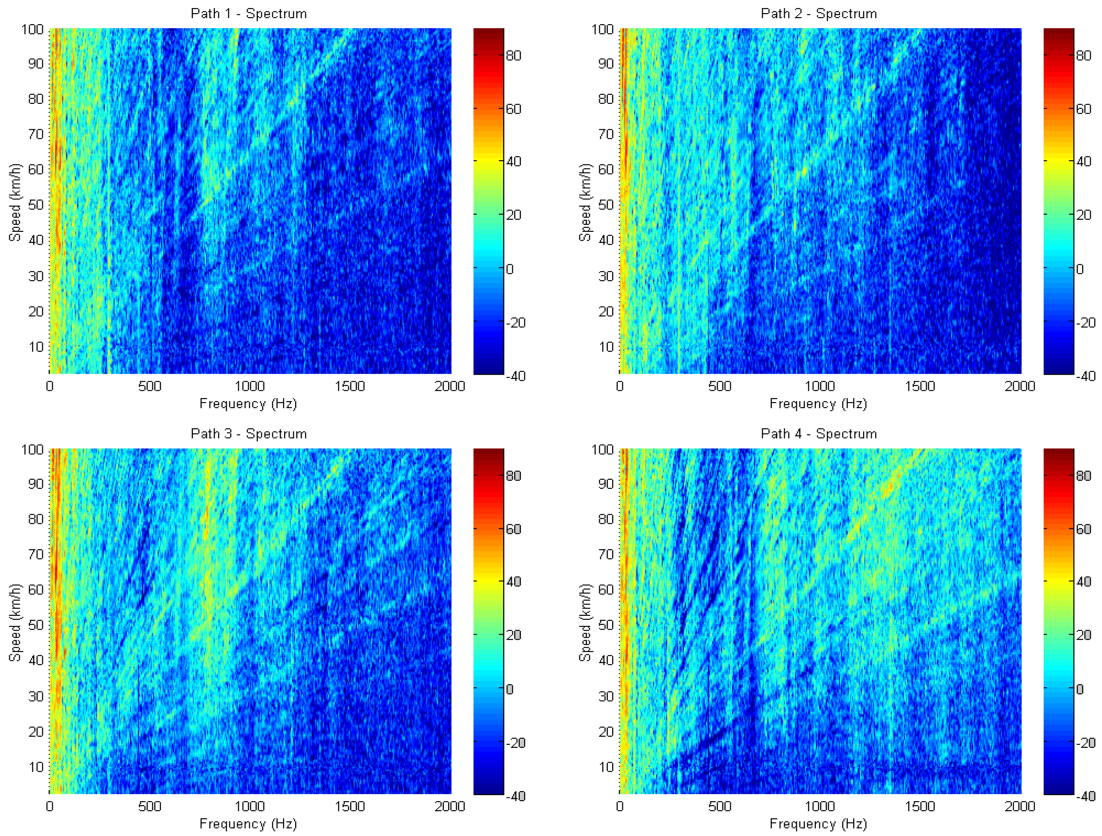


Figure 3a: Partial sound contribution from each path, in decibels

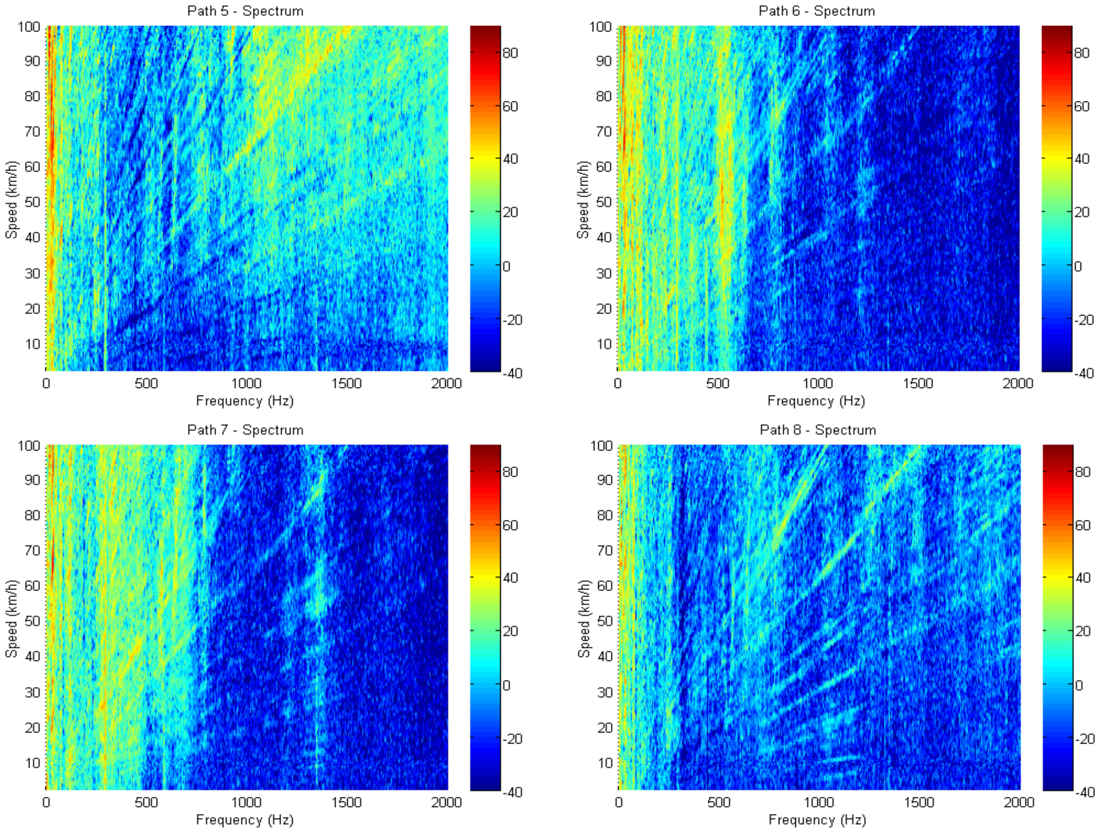
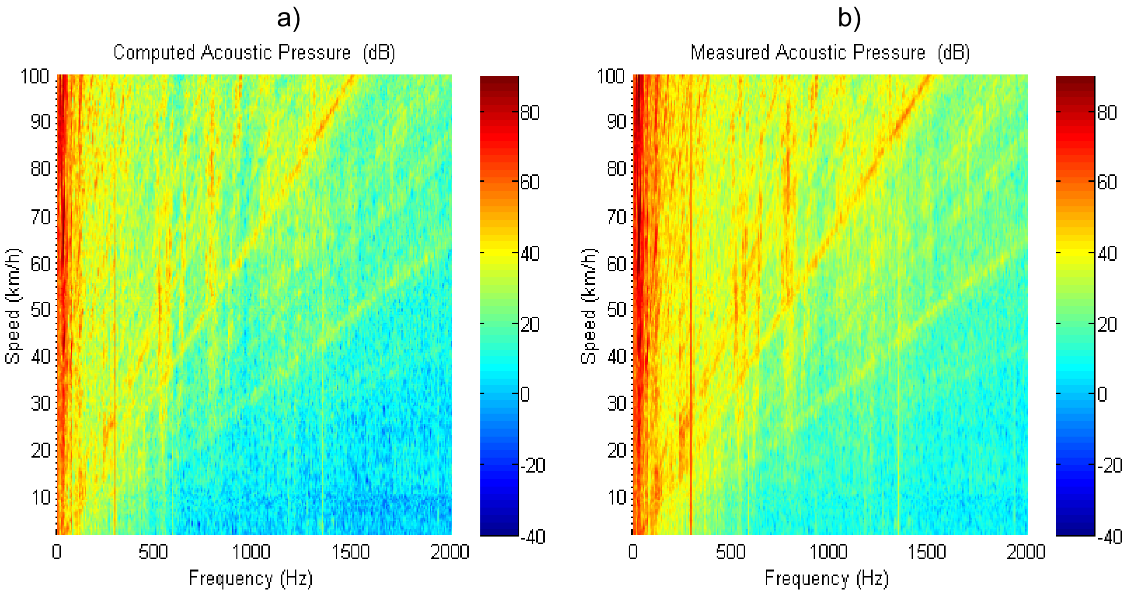


Figure 3b: Partial sound contribution from each path, in decibels



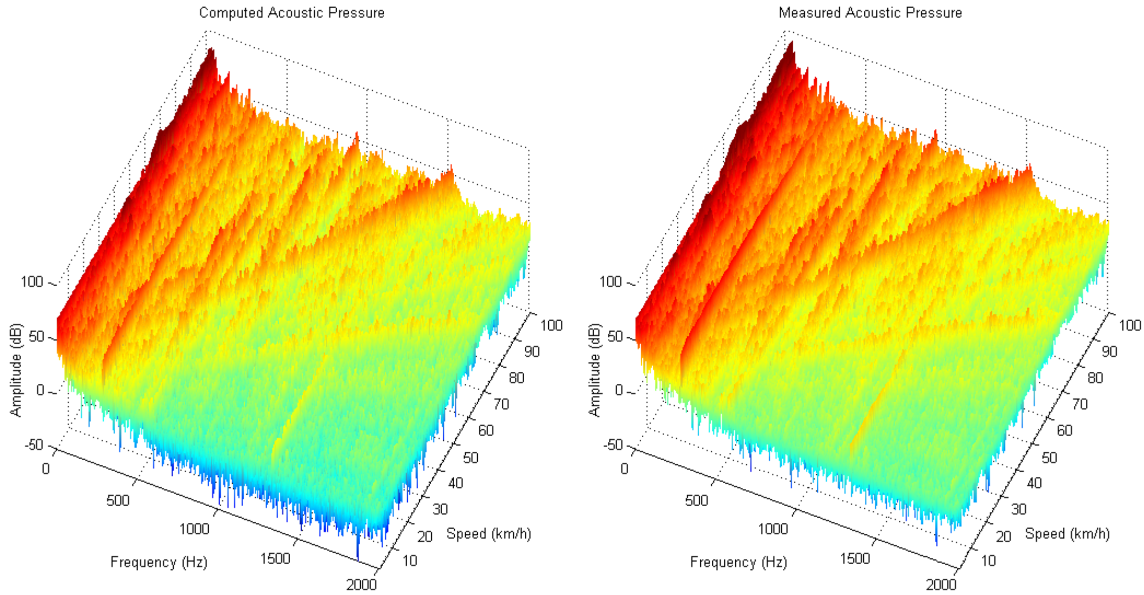


Figure 4: Comparison between Calculated (a) and measured (b) Acoustic Pressure signals

In Figure 4, 2 main signals can be identified. It is shown that in the calculated signal a small percentage of amplitude is lost.

This indicates that perhaps some of the paths are omitted because the OPA method is quite sensitive to this problem. The solution would be to add additional channels until a minimal difference in the amplitude of both signals is achieved.

However, the similar levels between the signals demonstrate the validity of the OPA method in environment. So, assuming their weaknesses, it can be used to perform an accurate NPA.

Therefore, the analysis of results achieved allows the determination of noise contribution from each path.

- In the low frequencies (less than 500 Hz), all the paths have similar contribution, taking special attention to X axis at mount 1 and 2 (6th and 7th paths) which have bigger impact.
- For the medium frequencies (between 500 Hz and 1000 Hz) the dominant paths are in Y axis at mount 3 (3rd path) and X axis at mounts 1 and 2 (6th and 7th paths).
- In the high frequencies (more than 1000 Hz) the paths of consideration are the rear suspensions points (4th and 5th paths) in the Y axis.

CONCLUSIONS

- Interior noise and accelerations in specified operating conditions have been measured in an electric vehicle.
- Noise transmissibility functions have been calculated and used in other tests to check their validity.
- The sound pressure calculated by the transmissibility functions has consistency with the sound pressure measured.
- Therefore, it is considered that the OPA method has been satisfactorily performed.
- The methodology is valid to use in EV.
- This is a fast and simple method but has its weaknesses because it is very sensitive to the missing paths.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the logistical support of the COST action TU1105.

REFERENCES

[1] Janssens K, Gajdatsy P, Van der Auweraer H. Operational Path Analysis: a critical review, LMS International NV, 2008.

[2] http://www.mitsubishi-motors.com/special/ev/4innovations/

[3] Putner J, Fastl H, Lohrmann M, Kaltenhauser A, Ullrich F. Operational transfer path analysis predicting contributions to the vehicle interior noise for different excitations from the same sound source, Internoise 2012, New York City, USA.

[4] Klerk D, Ossipov A. Operational transfer path analysis: Theory, guidelines and tire noise application, Mechanical Systems and Signal Processing, 24(7), 1950-1962, (2010).

[5] Vecchio A, Van der Auweraer H, Verhaeven E, Lenaers G. NHV Testing on Modern Vehicle Power Train Technologies, SAE International, 2004.