INVERSE TRANSFER PAHT ANALYSIS (ITPA), A METHODOLOGY TO SAVE TIME IN NVH ASSESSMENTS ON ELECTRIC CARS

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Cervantes-Madrid, Gines; Peral-Orts, Ramón; Campillo-Davó, Nuria; Campello-Vicente, Hector.
Universidad Miguel Hernández de Elche
Av. Universidad s/n,
03202 Elche, Alicante. España
E.mail: gines.cervantes@graduado.umh.es; ramon.peral@umh.es; ncampillo@umh.es; hcampello@umh.es

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ABSTRACT

The Inverse Transfer Path Analysis aims to assess, and determine, the contribution of the critical paths, which are transmitting car structure-borne noises and vibrations, from the vehicle’s vibration sources to the driver’s ear.

The cabin noise transfer function, from the involved attachment points and directions, can be simultaneously obtained by applying an impulsive noise source inside the cabin. This approach avoids the use of other time consuming classic procedures.

This methodology includes two types of tests, static condition tests in a semi-anechoic chamber and operational tests on a roller bench. The results assessment comprises the analysis of the noise contribution of each path, depending on the frequency and the vehicle speed range.

The NVH method presented here is proposed to study, identify and quantify noise transfer paths in a car structure.

RESUMEN

El objetivo del análisis inverso de los caminos de transferencia (ITPA) es evaluar, y determinar, la contribución del/los caminos críticos a través de los cuales se transmiten el ruido y vibraciones estructurales de un vehículo, desde las diversas fuentes del mismo, hasta el oído del conductor.

La función de transferencia del ruido en cabina, desde todos los puntos involucrados, se puede obtener simultáneamente mediante la aplicación de una fuente sonora impulsiva dentro del interior del vehículo. Este enfoque evita el uso de otros procedimientos que requieren mayor tiempo de ejecución.

Esta metodología incluye dos tipos de ensayos, primero un ensayo estático en cámara anecoica o semi-anecoica y segundo un ensayo operacional, o dinámico, en banco de rodillos. El estudio de resultados comprende el análisis de contribución de ruido individual para cada camino o canal, en función de la frecuencia y de la velocidad del vehículo.

El objetivo del método NVH presentado en este trabajo es estudiar, identificar y cuantificar los diferentes caminos de transferencia de ruido a través de la estructura de un vehículo.

1. INTRODUCTION

The increasing comfort expectations of customers, in the automotive sector, together with the need to meet the noise regulations, are a continuous challenge for car manufacturers. Noise, Vibration and Harshness (NVH) is one of the main areas related to the customer perception of quality in vehicles [1, 2]. Nowadays, with the increasing number of electric cars in the market, the interest in the field of noise and vibrations improvement has been intensified more than ever.

Short development times are becoming a constant challenge in terms of acoustic assessment for manufacturers vehicles in general and electric vehicles in particular. The ability to perform a fast NVH assessment on a new design has become essential for any manufacturer. Therefore, a fast and effective noise analysis tool would be very convenient to analyse the noise and vibrational behaviour of the vehicles.

Under the ITPA approach, the cabin noise transfer function can be simultaneously obtained by applying an impulsive noise source inside the cabin. This methodology avoids the use of other time consuming classic procedures and allows to perform NVH analysis in a considerable less time than classic Transfer Path Analysis (TPA) approaches, with better accuracy of results than Operational Paths Analysis (OPA) methods [3].

The main target of this paper is to describe the implementation of the ITPA methodology on an electric vehicle to assess the suitability of the ITPA for electric vehicles by studying the noise transfer paths contributions. The method presented in this work is focused on the body car structural noise transmission. Therefore, only the structure-borne noise, introduced to the cabin by the motor mounts and the suspension points, has been taking into account in this work.

2. IMPULSIVE NOISE SOURCE

The selected noise source is a specifically developed clapper, designed to operate as an impulse noise source [4]. This self-made source intends to operate as a quick alternative impulse sound source for experimental assessments in vehicle cabins or small spaces (Figure 1).

Figure 1: Clapper used as impulsive Noise source

An impulsive noise, or impact noise, means any sound with a rapid rise and decay of sound pressure level, normally lasting less than one second. Caused by sudden contact between two or more surfaces, or caused by a sudden release of pressure. This almost instantaneous increase in pressure, radiated by the clapper, is given by the integral of the pressure over a surface enclosing it (ISO-3744).

From the realized tests with a 2D camera acoustic, see figure 2, it is proved that although the clapper is a moderate size impulsive noise source, it has power enough at low frequencies to be used as a noise source for exciting structures. In comparison to other impulsive noise sources, the clapper produces acceptable peak sound pressure levels, is cheaper, easy to transport and meets target specifications.

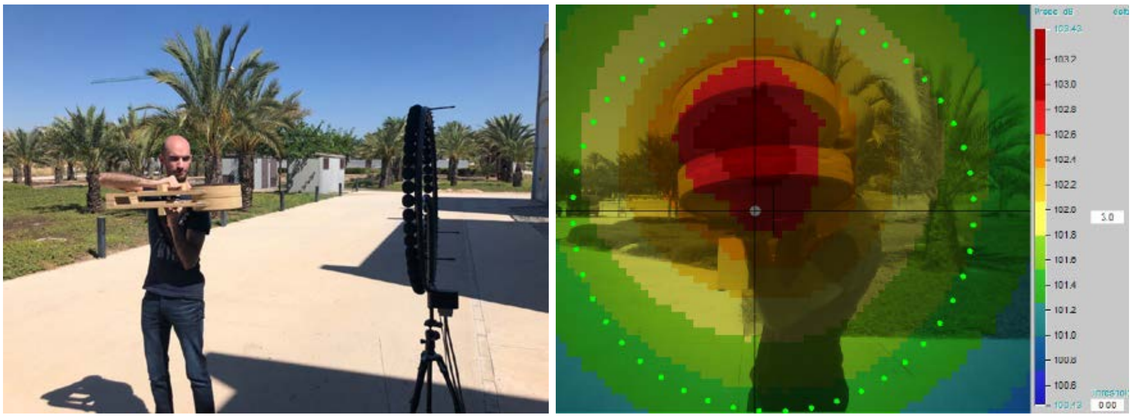

Figure 2: Directivity measurements of the Clapper

3. ITPA IMPLEMENTATION

ITPA implementation methodology is composed of three main stages: Stage 1- Static Test, to determine the noise transfer function; Stage 2- Operational Test, to acquire accelerations and sound pressure in dynamic conditions; and Stage 3- Calculations and results.

The selected electric vehicle for the implementation was a Peugeot Ion, a small electric car with the powertrain (electric motor and gearbox) over the rear axle. To capture accelerations 6 channels (paths) were instrumented on the engine mounts (3X and 3Y) and 2 more on the rear suspension supports (2Y). A microphone was installed in the cabin (driver's ears position) to record the acoustic pressure.

During static test in Stage 1, transmissibility concept is applied in an inverse way, to avoid the FRF estimation. It is based in the concept of mechanical-acoustic reciprocal transmissibility, which has been proved accurate enough in low and medium frequencies [5]. This approach of vibro-acoustic reciprocity has been often utilized in the measurement of Noise Transfer Functions (NTF), and widely demonstrated over time in numerous publications [6, 7].

To avoid the influence of any acoustic bouncing effect through the windows, the car was placed inside a semi-anechoic chamber (Figure 3). This way, the influence of any source from the exterior of the vehicle is also avoided.

Figure 3: Vehicle inside the semi-anechoic chamber

A series of static tests was performed, using the clapper to introduce an acoustic pressure inside the car, near to the driver position. Then, the acoustic pressure, and the corresponding produced accelerations at the defined points, were registered. An example of recorded data from a clapper test can be seen in Figure 3.

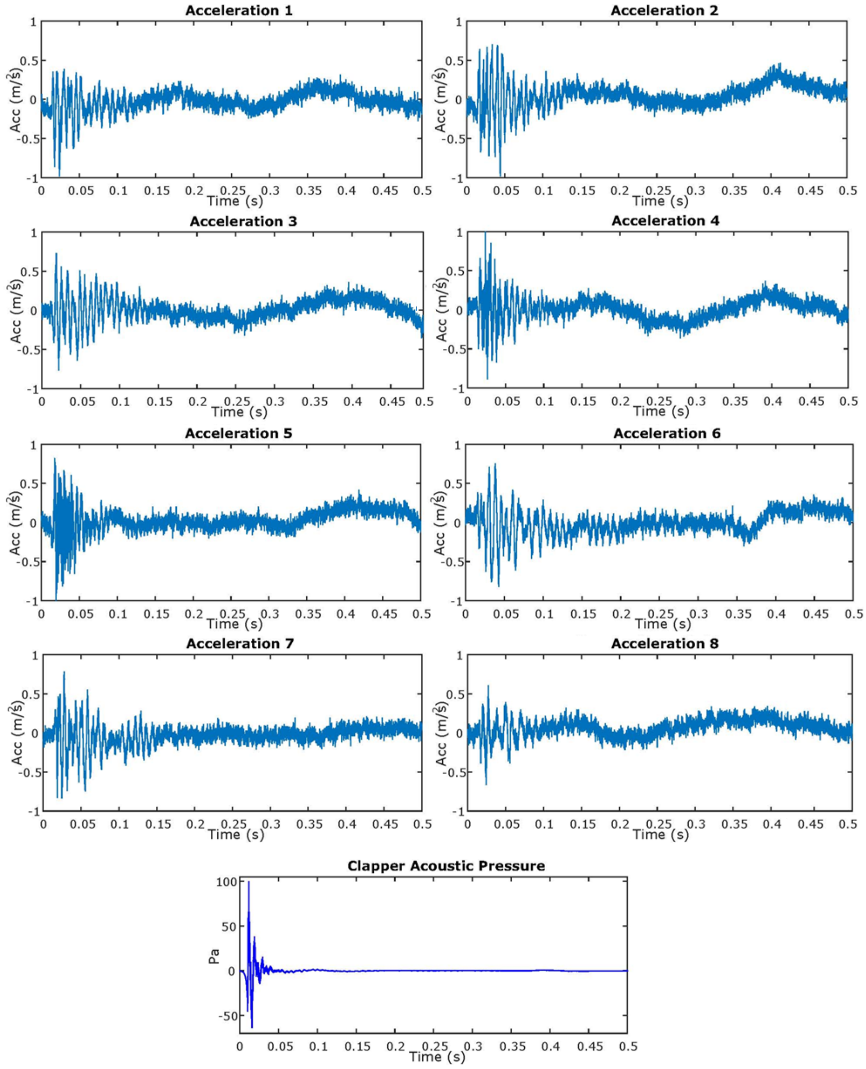

Figure 4: Recorded data from a clapper test in the time domain

To avoid possible errors due to manual manipulation of the clapper, a total of 40 clapper test were performed in this work. These tests were split into groups, in order to calculate the mean values. Then the obtained mean values were introduced in the calculations to obtain the noise transfer functions by the use of the inverse matrix method.

In the operational test, Stage 2, inputs will be accelerations and the output will be the acoustic pressure at the driver's head position, as only the influence on the cabin from structure-borne paths will be considered. For this dynamic test, the car was secured on a chassis dynamometer (Figure 5) and a run-up test from 0 to 100 km/h was performed.

Figure 5: Car installed on the roller bench

Accelerations and the acoustic pressure inside the cabin were recorded, using the already installed instrumentation in the car. The different signals recorded during this stage are presented in Figure 6.

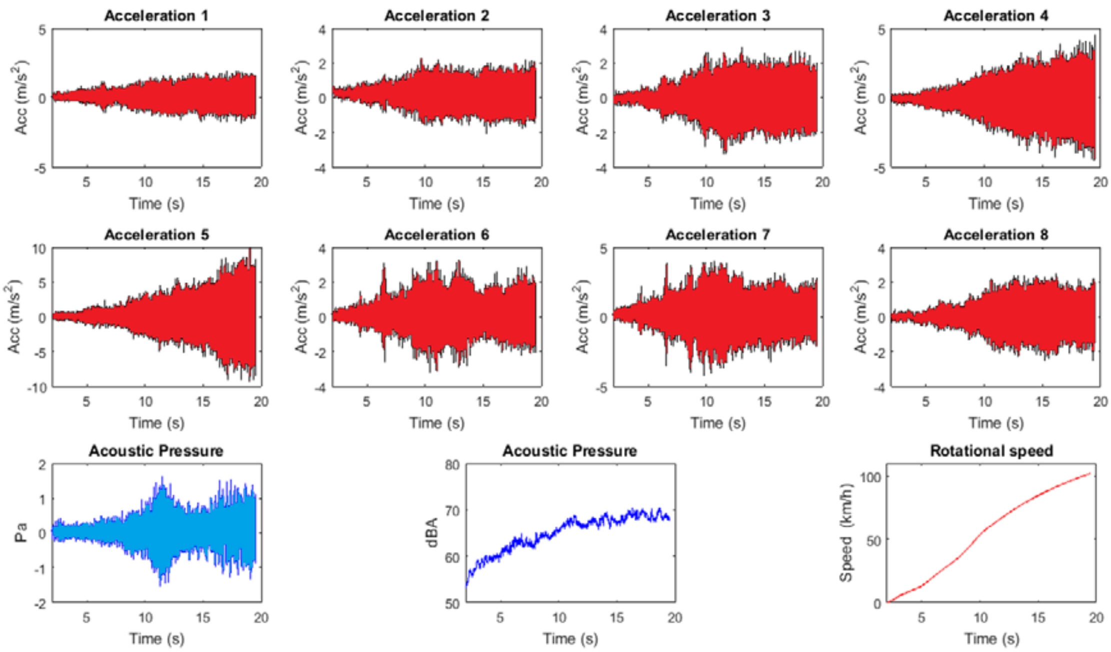

Figure 6: Example of the data gathered during the dynamic test

Once the data from the dynamic part has been obtained, the ITPA calculated acoustic pressure can be calculated. Thus, it will allow to determine, not only the global noise perceived in the cabin, but also to identify the particular behaviour of each considered path, and its partial contribution to the cabin noise, depending on the frequency.

As the ITPA incorporates both static and operational tests, the comparison between the calculated acoustic pressure and the measured one is conclusive enough to assess the validity of the results, and thus, the suitability of the methodology for this application. Figure 7 shows two sound pressure level/frequency/speed charts, corresponding to the comparison between, calculated or computed (top) and measured (bottom) signals. As can be seen, both spectrum show an adequate agreement, and all the main harmonics can be clearly identified in both charts.

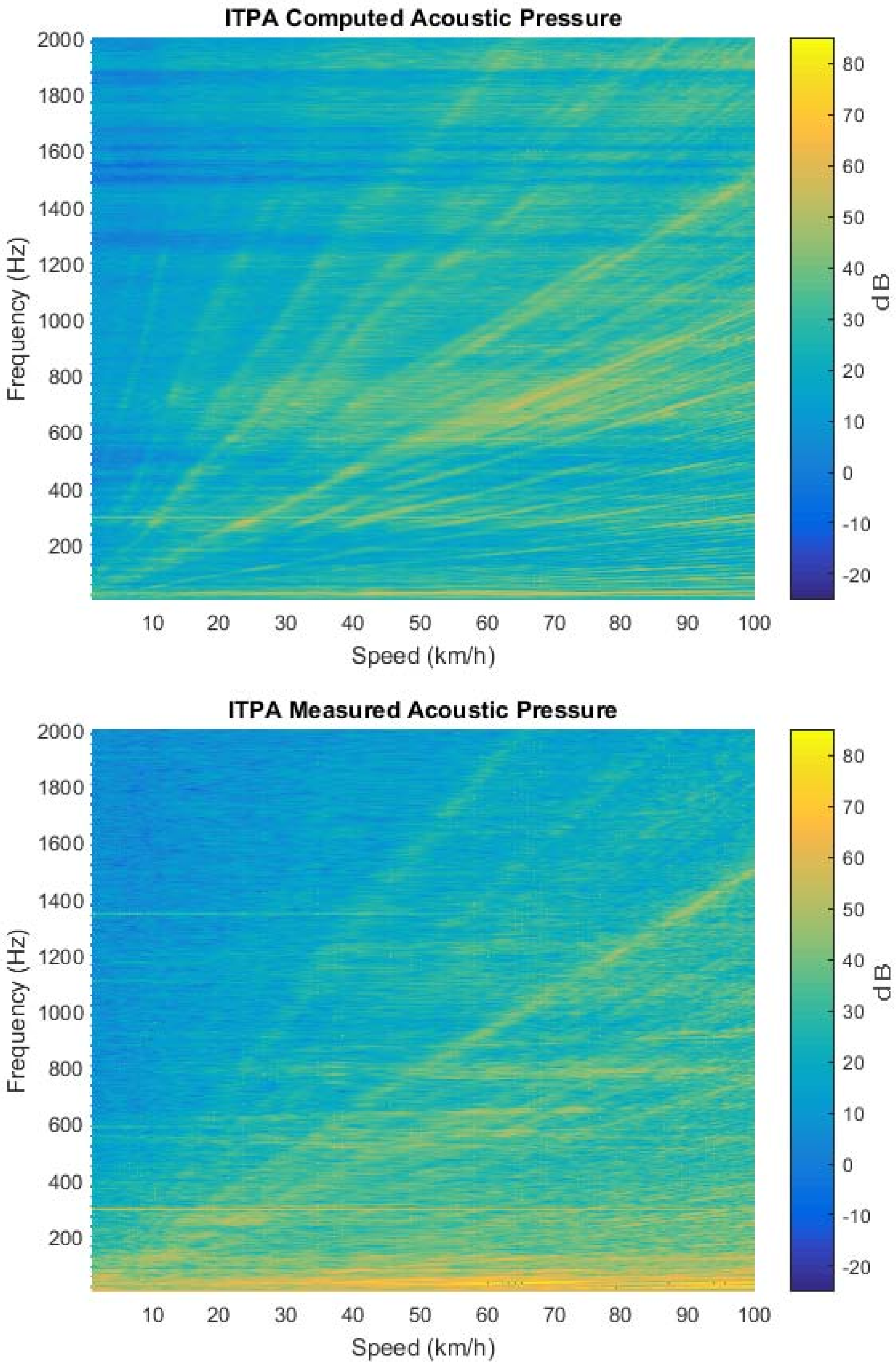

Figure 7: Calculated Vs measured acoustic pressure

4. CONCLUSIONS

An experimental test was conducted on an electric car to prove and validate the applicability of ITPA methodology for electric vehicles. Conclusions from this research can be summarized as:

1- Adequate agreement between measured and predicted noise allows assessing the critical paths on the system. Even without considering the air-borne effect, and with the limited paths considered, the harmonics match with both signals.

2- Based on the empiric experience [3, 8], the ITPA methodology is a suitable methodology to perform NVH analysis electric vehicles.

3- The model can provide accurate conclusions to determine the dominant paths involved in the noise transmission, and the identification of both mechanical or electrical sources of noise in the cabin.

Thus it can be concluded ITPA is a useful tool to perform NVH assessments on electric cars. The method is leading to the identification of path contributions to the cabin noise and delivering correct conclusions in car noise assessments. ITPA can be used as NVH method to identify noise contributions from electric powertrain and controllers in electric vehicles.

Some tests are under study to better understand the energy distribution of the Clapper excitation using a 3D acoustic camera, see Figure 8.

Figure 8: Tests to study the sound distribution of the Clapper in a car cabin

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