Applied Acoustics 118 (2017) 58–65

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical note

Noise emission from alternative fuel vehicles: Study case

David Ibarra *, Ricardo Ramírez-Mendoza, Edgar López

Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias, Av. Eugenio Garza Sada 2501 Sur, Col. Tecnológico, C.P. 64849 Monterrey, Nuevo León, Mexico

ARTICLE INFO

Article history:
Received 13 September 2016
Received in revised form 9 November 2016
Accepted 14 November 2016

Keywords:
Road traffic noise
Engine noise emissions
Tyre noise emissions
Alternative fuel vehicles

ABSTRACT

Noise pollution has become a source of social tension, with economic development on one hand and quality of life on the other. The number of vehicles on the road is increasing constantly, especially in urban areas. As a consequence, environmental pollution has also increased, not only due to fuel emissions harmful to people, but also due to noise pollution; therefore, the control of the acoustic environment has turned out to be a key issue and a technological challenge.

According to Ibarra et al. there have been recent studies on the quantification and characterization of noise emitted by vehicles in the near and far fields, but this kind of work has mainly been developed for internal combustion vehicles fuelled by diesel or petrol. With new emerging technologies aimed at improving world social and environmental conditions, new alternative fuel vehicles are appearing around the world, especially in large cities. These new vehicles have not yet been characterized regarding their noise emissions. The aim of this work is to characterize and quantify the level of noise emitted by alternative fuel vehicles, such as hybrid and electric vehicles, for both near and far fields. To achieve this, it would be very useful to incorporate simulations of noise mapping.

Experimental results of this work demonstrate that hybrid and electric engines have made important contributions towards reducing engine noise in suburban and urban traffic, at least 10 dBA less than diesel or petrol vehicles; however, noise from the tyre-ground interaction remains the main source of noise, especially in suburban roads at high speeds.

1. Introduction

Any study aimed at increasing comfort for humans should consider the sounds in their surroundings, and in our case, the noise generated by vehicles is one of the most important aspects of urban life, as shown by Van Mierlo et al. [1] or in a deeper analysis by Ibarra [2]. In addition, according to Parry et al. [3], climate change, economic policies and petroleum production have recently increased the desirability of vehicles with alternative sources of power, which appear to offer certain advantages in many ways compared to conventional cars. These two ideas converge on the fact that noise emission by alternative fuel vehicles, is a critical point to be analysed in the near future.

Conventional studies of these changes, such as social studies of technological systems in vehicles [4] or the challenges of integrating electrical systems in conventional systems [5] and other research are typically focused on aspects such as contamination by particulate emissions of carbon dioxide, but only a few works have researched the noise contribution in alternative energy vehicles such as hybrid and electric.

The characterization of alternative energy vehicles regarding noise emission is important due to the fast growth at local and global levels, since, eventually, efforts will focus on their analysis. It is worth noting the study by Sandberg et al. [6] where they point that electric vehicles are so quiet, that their lack of noise could pose a risk for certain groups in society, e.g. blind pedestrians and cyclists mainly. However, they analysed only the perception of the presence of a car by its noise, the distant field, but there was not enough detail regarding the methodological procedure in a real urban scenario or at least in an experimental scenario to parameterize the noise emission of these vehicles. While it may be necessary to perceive the approach of an alternative fuel vehicle, it is assumed that such a vehicle would be totally silent. However, the noise generated by the tyres has not been measured effectively e.g. [7].

Thus, in order to face the challenging goal of maintaining a pleasant acoustical environment with a continued trend towards more vehicles, new and audacious emission control measures are needed. With this aim, we validate in this work the methodology for measuring the contribution of each individual alternative fuel

* Corresponding author.
E-mail address: david.ibarra@itesm.mx (D. Ibarra).

http://dx.doi.org/10.1016/j.apacoust.2016.11.010

vehicle to the whole road traffic noise [8]. On-board measuring devices have been previously used for driver identification purposes [9], for measuring the quality of traffic flow [10], and for measuring the noise contribution of diesel and petrol vehicles [11–14].

2. General methodology

The tests are made along to the suburban an urban circuit with different drivers, and with different driving modes provided by the vehicles.

For each of these tests, the signals were recorded from each microphone through the template of the PULSE system, and we processed them to obtain the following data:

- The time evolution of the equivalent level of 1 s ($L_{eq,\ 1s}$) each of the microphones and for each of the runs, along the urban and suburban courses.
- The overall equivalent levels, L_{eq}, of suburban and urban courses, of engine and rolling noises for each of the driving modes.

$$\langle L_{Aeq} \rangle_T = 10\log_{10}\left[\sum_{Ti} 10^{L_{eq,T_i}/10}\right], \quad (1)$$

with $T = \sum T_i$.

- The level histograms along the runs, e.g. the time percentage that the equivalent level is in each level band.
- The noise levels estimated in the far field.

Since most regulations are based on noise levels measured at the far field, a study of the near-field to far-field sound propagation in vehicles is pertinent. Therefore, analyse the relationship between the noise measured at the near field and the noise radiated to far field. Separated filters are described then to extrapolate the two near field noise levels to the far field, where they will be added energetically. The main factors influencing these extrapolation filters are the geometrical spreading and the interaction with the ground [8].

The sound pressure level at the far field point will be

$$L_{m3}(\omega) = L_{m1}(\omega) + L_{13}(\omega) \oplus L_{m2}(\omega) + L_{23}(\omega), \quad (2)$$

where $\oplus$ stands for energetic (logarithmic) summation. The first term of this summation includes the attenuation between the engine microphone and the far field point. The second term comprises the sound pressure loss between the tyre microphone and far field point.

3. Study case

The system used in this work includes two acoustic sensors (electret microphones) to measure the contribution of the two main noise sources in conventional vehicles, namely, the tyre-ground interaction noise, and the engine noise. In the case of alternative vehicles tyre-ground interaction is the primary source of noise, with a smaller contribution from the engine. Fig. 1 shows the location of microphones near the noise sources of vehicles. Simultaneously, information about the driving performance can be picked up from the CAN BUS interface of the vehicle. Analysis of coincident acoustical/driving performance data in real driving conditions will allow setting some correlation, if any, between the noise emitted by individual alternative vehicles and the driving performance [15–17].

Typically, commercial vehicles with alternative fuels are classified by their source of power, mainly into hybrid or electric. For the purpose of this study, two vehicles (described below) were used. They were selected as being representative of vehicles widely found in circulation around the world, especially in big cities. These vehicles are compact, of medium capacity and with an average power of 100 kW (135 hp). According to Armero [18], the vehicles selected represent 0.05% of the world vehicles.

Since the market proportions of hybrid and electric engines in Mexico are 99% and 1%, respectively, of the total of alternative vehicles, it seems practical to analyse both types in this study. Taking also into account the vehicle recorded statistics published by AMDA [19] (Mexican Association of Vehicle Dealers), the chosen vehicles were:

- Vehicle 1: Toyota Prius Hybrid
- Vehicle 2: Nissan Leaf Electric,

Two driving courses were chosen in the Tlalpan neighbourhood, in the south of Mexico City. The suburban road, runs along the Periferico ring road, which supports a traffic density of 600,000–800,000 vehicles per day. It has a length of 7 km (5.4 mi), with three lanes in each direction, and a maximum speed limit of 80 km/h. The L_d in this area, according to the above referred preliminary noise map of Mexico City, is >85 dBA.

The urban road includes streets with speed limited to 50 km/h, supporting a traffic density from 120,000 to 140,000 vehicles per day, with a L_d of 75 dBA. 50% of the circuit runs through one way streets of three lanes, while the other 50% runs roughly along streets with four lanes in each direction. This urban road is approximately 8.4 km long and is equipped with 24 sets of traffic lights.

Two professional drivers were selected for testing the two vehicles. Two microphones were connected to a PULSE Labshop system to measure the engine and tyre-road interaction noise at the near field of the vehicles. Concurrent driving conditions and radiated noises were measured with the vehicles running in real conditions, e.g. sharing the urban and suburban roads described above with the normal traffic. Previously, both microphones had been adjusted with a sound level meter. Driving condition parameters were measured through the vehicles' CAN BUS system, which includes an ODB2 module [20]. This system is interfaced to the acquisition system through an ELM327 probe, allowing picking up information from three signals, namely, the engine speed, the engine load, and the vehicle speed.

3.1. Test procedure

Once the vehicles had been fitted with the test instruments, the drivers were asked to run both courses, suburban and urban, with each vehicle, following the current traffic conditions. The hybrid vehicle offers three driving modes (normal, eco and power) and the electric vehicle offers two driving modes (normal and eco), and all the modes were tested.

The tests were conducted at different times, morning and evening, and on different days of the week. Acoustical and driving condition measurements were synchronously triggered at some starting point of each circuit. Once the circuits were completed, the vehicles returned to the laboratory for transferring the data to the workgroup server for further post-processing and analysis.

Besides the microphones, for acoustical data, and the CAN BUS system, for driving conditions data, a GPS was used to record information of the vehicle position, speed, travelled and time, and whether the vehicle was stationary or moving.