Sound level study of a hybrid car

G Staneva, K Dimitrova, R Ivanov and G Kadikyanov
University of Ruse, Department of Engines and Vehicles, 8 Studentska Str., 7017
Ruse, Bulgaria

E-mail: glstaneva@uni-ruse.bg

Abstract. One of the main reasons for the urban noise are the cars. When the hybrid cars are
moved in low-speed mode, reduced noise is supposed. In the presented paper have been made
comparative analysis according to standard methods of the external and internal sound levels of
a hybrid car. The experiment at different speeds in two modes – using ICE and using electric
traction were carried out. The results of the measurements are visualized in graphs and tables.
They show variation of external and internal sound levels at different speeds in separate octave
bands. Spectral analysis at each speed is done. The results show changing of sound level vs speed
and noise predominant maximums at respective frequencies.

1. Introduction
Noise is one of the main reasons for the deterioration of people's health. It reduces labor productivity,
causes the appearance and development of nervous, vascular and other diseases and affects life duration.

According to [1] noise is any unpleasant or unwanted sound. A sound field is the area in which the
sound waves reproduce. At each point of the sound field, the pressure and velocity of movement of the
air particles change over time. The difference between the instantaneous full pressure value and the
average pressure observed in an unburnt environment is called the sound pressure $p$. The sound pressure
measuring unit is pascal [Pa]. The intensity of the sound $L$ is measured with the Bell unit [B], which in
the practice is increased 10 times – decibel [dB].

In today's increased use of transport equipment, the problem of combating noise is of great
importance. Increasing urban traffic intensity leads to a significant increase in the noise level (sound or
sound pressure) in the larger cities.

Vehicle noise as a negative impact on people can be seen from two sides: noise in the car where the
driver's and passenger’s seats are situated, and noise from the vehicle - the so-called external noise,
affecting all residents of the modern city.

In order to limit the continuous increase of the noise level and to preserve the human health in recent
years in many countries, norms have been developed and introduced for the permissible noise levels for
working, living and relaxation [2, 3]. The work against noise has to be conducted in several directions,
but one of the most effective is to reduce its level in the sources that cause it.

Noise sources in the vehicle are separate units, mechanisms and aggregates. For example, according
to [4, 5] the internal combustion engine (ICE) is one of main noise and vibration generator. Other types
of noise are: the noise caused by the interaction of the vehicle with the air - aerodynamic noise and the
noise caused by the interaction of the tires with the road surface. The noise level of the individual vehicle
is the sum of the noise energies generated by the separate sources [2, 6, 7].
Usually in hybrid cars, there are two main modes of operation: operating with internal combustion engine (ICE) and with an electric motor. When the hybrid car is running on an electric motor mode, one of the main sources of low-speed noise is reduced. This is an indisputable advantage in urban traffic, but a potential problem under the same conditions. The lack of typical ICE noise makes the vehicle discoverable at shorter distances, and this may be a problem for the elderly people, young children, people with disabilities, and people who are not used to the urban movement.

The noise also depends on the tire profile and the movement of the cars on different road surfaces. According to [8] the reasons for the occurrence of noise are:
- flickering of the tire's pages due to periodically occurring deformations when rolling;
- periodic displacement and suction of air in the profile channels upon movement (air-pumping);
- the greatest share of the sound energy of the rolling radius is the impact on the profile teeth (blocks) when they enter into contact with the road.

The purpose of this study is to make a comparative analysis of the measured maximum intensity of noise in ICE mode and electric motor mode of a hybrid car at different motion speeds. There have been made researches of the external and internal levels of the sound.

2. Method and equipment
The study was conducted with a Toyota Yaris HYBRID (Figure 1) with technical characteristics as shown on Table 1 [9].

The vehicle tires are Dunlop Sport Fastresponse 175/65 R15 84H. The air pressure in the tires is 0,25 MPa. Class of tires C1 corresponds ‘passenger car tires’ in [10].

| Main technical characteristics | Toyota Yaris (P3) Hybrid |
|-------------------------------|-------------------------|
| Modification                  | 1,5 HSD Hybrid 100 Hp   |
| Max Power / engine speed      | 55 kW / 4800 min⁻¹      |
| Max torque / engine speed     | 111 Nm / 4400 min⁻¹     |
| Max power of electric system  | 45 kW                   |
| Max torque of electric system | 207 Nm                  |
| Capacity of the battery       | 0,94 kWh                |
| EVRO standard                 | EURO V                  |
| Tires                         | 175/65 R15              |
| Maximal speed                 | 165 km/h                |
| Time for acceleration from 0 to 100 km/h | 11,8 s |
| Empty weight                  | 1 120 kg                |

Figure 1. Studied vehicle Toyota Yaris HYBRID.

Figure 2. Experimental hard-grained asphalt surface.
2.1. Measurement of the external sound level
Measurement of the external sound shall be carried out in a free sound field on hard-grained road surface with cracks (Figure 2). The site of testing corresponds to the requirements as described in [11, 12]. The location of the microphones during the tests is shown on Figure 3 as they are located of height 1,2 m over the road.

Figure 3. A scheme of the external noise test with distance of the microphone from the middle line of vehicle passing 7,5 m.

The measurements are carried out in the following order:
1. In electric motor mode – the car moves at a steady speed of 20, 30, 40 and 50 km/h in each test. At a speed over 50 km/h, the electric motor mode is impossible.
2. In ICE mode, the car moves steadily at 60 km/h to 120 km/h in each test.
In the tested area shown at Figure 3 a recording is made with the device (Figure 5).

2.2. Measurement of the internal sound level
While measuring the internal sound level, the vehicle is moving on the road as described in the methods for measurement of the external sound level. At a distance less than 25 m near the test site there are no barriers or buildings. At the time of the tests all the doors, the windows and the hatches are closed. The microphone is placed near the ear of the driver (at 700 mm over the seat and at 200 mm aside the longitudinal vertical plain of the seat) oriented forward direction of the moving car (Figure 4) [13].

Figure 4. A scheme of the location of the microphone during the measurement of the parameters of the internal sound level.
Experimental studies were performed with a VI-410 Quest Technologies [14]. It is a digital, four-channel device for measurement and analyses of vibrations with channels 1, 2 and 3 using channel 4. VI-410 has internal memory 32 MB for memorizing of the measurement parameters for all the channels for a long time period. The results of the measurements are visualized and processed with the help of software Quest Suite Professional II.

![Figure 5. General view of the VI-410 Quest Technologies device.](image)

The device is equipped with sound calibrator having the possibility to emit waves with sound level 94 or 114 dB at frequency 250 or 1000 Hz (Figure 5). Before starting to work with the device VI-410 and after finishing the work, it has to be calibrated (Figure 6) [14].

![Figure 6. Sound calibrator QC-10.](image)

Human ear can perceive sounds of different frequencies and levels as equally strong. Differences in the perception of sound depending on the frequency and the level make it necessary to use frequency corrected sound pressure levels. The adjustment is a setting of sound pressure levels and applies to each frequency range.

The sound intensity of the correction curve $A$, expressed in dBA, best suits the subjective perception of sounds at low sound pressure levels [6, 15].

Current sound level measurements are performed using correction filter $A$. 
3. Investigation and results
At the end of each measurement, the data is stored in the memory of the VI-410 measuring device.
With its help, the results can be transferred into tables and graphics.

3.1. Results from the external noise level
For each of the tests, the maximum sound level values that correspond to the level of the vehicle passing through the microphone line at a distance of 7.5 m from its central axis (Figure 3) are taken into consideration.

Figure 7 shows, as an example, the change of the sound level in octave bands as well as in the equivalent summary value (1st left column).

![Figure 7](image)

**Figure 7.** External sound level in third octave bands at speed of 40 km/h.

Figure 8 shows the change of the external sound level (dBA) at different velocity, for the dominant octave band. It is clearly seen that the increase of the car speed leads to increase of the noise level. Slight dispersion of the parameters at 50–60 km/h is seen due to the change of the operational modes of the car – from movement with electric motor mode to ICE mode.

Table 2 shows the summarized data for the change of the external sound level depending on the speed by octave bands at electric motor mode and ICE mode.
Figure 8. The change in the level of external sound L at 1000 Hz depending on speed V.

Table 2. The measured maximum values of the external sound, dBA.

| V, km/h | 31.5 | 63  | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---------|------|-----|-----|-----|-----|------|------|------|------|-------|
| 20      | 27.5 | 30.2| 33.8| 42.3| 41.1| 43   | 45.7 | 39   | 41.4 | 42.2  |
| 30      | 27.5 | 31.7| 37.4| 47.6| 43.6| 52.7 | 47.5 | 41.4 | 42.8 | 43.1  |
| 40      | 23.8 | 33.4| 39.6| 51.7| 52.4| 59.3 | 54.3 | 45.5 | 43.2 | 42.4  |
| 50      | 27.5 | 33.7| 40  | 55.1| 52.4| 62.2 | 57.5 | 48.6 | 42.8 | 42.1  |
| 60      | 33   | 33  | 42.2| 56.4| 52  | 65.7 | 60.5 | 51.2 | 46.1 | 42.5  |
| 70      | 27.4 | 37.6| 49.6| 57.4| 56.6| 68.2 | 62.1 | 52.9 | 47.3 | 42.3  |
| 80      | 27.5 | 37.3| 48.4| 58.7| 56.7| 69.6 | 65.4 | 55.9 | 48.2 | 43.7  |
| 90      | 21.1 | 41.8| 48.6| 60  | 62.6| 72.7 | 67.3 | 57.1 | 51   | 44.2  |
| 120     | 21.1 | 42.7| 52.3| 62.4| 61.1| 74.1 | 70.7 | 62.2 | 55.5 | 45.2  |

At low frequency up to 125 Hz and low velocity up to 60 km/h, the level of the sound stays close to the background noise, at higher velocity it slightly increases. At frequency 250 Hz and 1000 Hz there are local extremes of the sound level, which increase their values together with the increase of the speed.

Table 2 shows that at ICE mode at speeds higher than 60 km/h and 250 Hz, the change of the sound level is negligible. The main noise source at that working mode is the ICE. Due to the automatic gear box the RPM of engine is changed insignificant.

At frequency 1000Hz more extreme increase of the sound level is observed, which is probably due to the tires, which are the main sources of external noise of the high-speed moving cars.
3.2. Results of the internal sound level

For the tests of the internal sound level it has been used the same measurement device VI-410. The used methods are described here above. The results are processed by the same specialized software product (Quest Suite Professional II) and are presented and visualized in a way similar to the results for the external sound level.

Figure 9 shows the change of the internal sound level in (dBA) depending on speed, for the dominant octave band. It is seen that speed increase leads to increase of the level of the noise and no substantial deviations are shown upon changing of the working modes from electric motor to ICE.

![Figure 9](image)

Figure 9. The change of the internal sound level at 125 Hz depending on the different speeds.

Table 3 shows summarized data for the change of the internal sound level depending on the speed in octave bands. It is seen that the level of the sound has a maximum at 125 Hz frequency. This is probably a result from the work of the powertrain.

| $V$, km/h | 31.5  | 63   | 125  | 250  | 500   | 1000  | 2000  | 4000  | 8000  | 16000 |
|-----------|-------|------|------|------|-------|-------|-------|-------|-------|-------|
| 20        | 39.7  | 46.6 | 51   | 41.7 | 40.9  | 37.8  | 35.6  | 36.8  | 42.7  | 42.2  |
| 30        | 44.9  | 48.5 | 52.3 | 46.9 | 43.3  | 39.8  | 36.5  | 36.6  | 40.7  | 42.3  |
| 40        | 46.6  | 51.4 | 57   | 52.9 | 49.9  | 44.6  | 39.6  | 38.7  | 42.5  | 42.2  |
| 50        | 48.1  | 52.2 | 58.9 | 54.3 | 51.9  | 47.1  | 41.9  | 37.2  | 42.6  | 42.2  |
| 60        | 48.7  | 52.3 | 61.6 | 56.1 | 54.9  | 50.1  | 45.3  | 38.5  | 41.8  | 42.2  |
| 70        | 48.6  | 51.9 | 59.8 | 56.8 | 56.7  | 52.8  | 47.5  | 39.2  | 42.4  | 42.2  |
| 80        | 52.6  | 51.7 | 61.8 | 59   | 58.1  | 54.4  | 49.3  | 40    | 42.4  | 42.3  |
| 90        | 47.6  | 53.8 | 63.8 | 60.4 | 59.7  | 61.1  | 52.1  | 43.7  | 42.8  | 42.3  |
| 120       | 50.6  | 57.5 | 66   | 64.7 | 64.8  | 61.1  | 56.6  | 49.4  | 47    | 42.8  |

From comparing the external sound level (Table 2) and the internal sound level (Table 3), it is seen that on Table 3 is missing an extreme at frequency higher than 1000 Hz. The reason could be the isolation of the sound from the tires in the hybrid car coupe.
4. Conclusions
A study, concerning sound level of external and internal noise of a hybrid car Toyota Yaris was carried out. The experiments were realized at different speeds in two modes – using ICE and using electric traction. The speed varies from 40 to 120 km/h. The obtained results give possibility to make some conclusions and generalizations.

The general internal and external sound levels increase with increasing of the car speed, following the relation, near to exponent.

There is not clear jump in the curves of internal and external sound levels when the car passes from electric to ICE traction. It is due to the good exhaust system of the car. Significant change in internal noise when changing the mode of power source is not observed due to the good noise isolation of the passenger compartment from the surrounding area. The smooth increase of internal noise can be explained by the dominating acoustic emissions from the vehicle construction vibrations.

When measuring the external noise of the vehicle there are observed two maximum values of external sound levels at 250 Hz and 1 kHz for each speed.

Due to the transforming properties of the construction, the internal noise spectrum has predominant maximums at lower frequencies (125 Hz and 500 Hz).

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