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A Mechanical Acoustic Vehicle Alerting System (MAVAS) for electric vehicles

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ABSTRACT
The increase in the fleet of electric and hybrid-electric vehicles has revealed the danger of their low detectability. When these vehicles circulate at low speed, their sound emissions increase the risk of pedestrians being struck. Vehicle manufacturers have found the solution by providing quiet vehicles with an on-board Acoustic Vehicle Alerting System, AVAS. In addition, in January 2017 the European Regulation nº138 was published to limit the acoustic characteristics of these devices in order to guarantee their detectability. Currently, all these devices are based on speakers that emit an artificial and canned sound, not associated with a moving vehicle. On account of this, a system consisting of gears emitting a mechanical sound is proposed, Mechanical Acoustic Vehicle Alerting System, MAVAS. This paper details the model of a cylindrical dry spur gears system and its experimental validation to predict the sound emitted.

Keywords: Electric vehicles, warning sounds, AVAS, noise.
I-INCE Classification of Subject Number: 11

1. INTRODUCTION

Several studies show the inherent danger of silent circulation from electric and hybrid electric vehicles. This is especially important from pedestrians and cyclists in urban environments who cannot detect properly the proximity of this type of vehicles. Previous publications [1] indicate that twice more accidents can occur when the vehicles involved are quiet. Boarded warning systems, which advice the presence of vehicles with sound alerts, have been developed to solve this problem.

In January 2017, the regulation UNECE Nº 138 [2] was published after the appearance of different kinds of warning systems. This regulation has the purpose of limiting the sound emissions: establishing minimum and maximum sound levels and confining the frequencies allowed.

Studies like the eVADER project [3] show that the detection distance of a combustion engine vehicle by a peasant is 36 m, whereas in the case of an electric vehicle equipped with a boarded warning system it is reduced to 18 m. This fact is due to psychological and perception factors and it is not produced by different sound levels reached by both types of vehicles.

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In fact, some automotive companies have been developed their own warning systems, like the VSP technology from Nissan [4] or the VPN from Toyota [5]. Both systems use speakers emitting a varying in frequency tonal sound depending on the velocity of the vehicle. Apart from cars manufacturers, other companies have specialized in marketing of these gadgets, like Enhanced Vehicles Acoustics [6] or EC Tunes [7]. All these manufacturers are focused on electronics systems that emit an artificial and canned sound, very far from the distinctive sound of an internal combustion engine vehicle (ICE).

This document describes the earliest phases of developing of a new kind of boarded warning system able to improve the perception of quiet vehicles. The main concept behind the Mechanical Acoustic Vehicle Alerting System (MAVAS) is to emit a mechanical sound closer to the emitted by an ICE vehicle rather than the produced by an electronic warning system.

For that purpose, a mathematical model is used as a designing tool to predict the noise generated by MAVAS confirming that it is adequate to the regulation.

2. REGULATION

The current European regulation is the UNECE regulation number 138 [2] which details the homologation of silent road transport vehicles with regarding their lack of audibility.

The regulation was issued in January 2017 having an amendment in August 2017. The regulation applies to vehicles with at least 4 wheels which can circulate without running any internal combustion engine, intended for both passenger transport and goods. These vehicles must be equipped with an Acoustic Vehicle Alerting System, AVAS.

The speed range for the AVAS operation is the range of greater than 0 km/h up to and inclusive 20 km/h. The tests on the vehicle equipped with an AVAS are carried out at a constant speed, these being: forward test, backward test, and frequency change test.

The following is a summary of the AVAS sound conditions that must be met in these tests. The regulation also details the conditions under which the tests must be carried out, which can be in motion or with the vehicle stopped.

- Constant speed test:
  - Have a minimum overall sound pressure level corresponding to the test speed according to Figure 1.
  - Have at least two of the octave bands in Figure 1, and at least one of these bands must be less than or equal to the 1600 Hz band. Each band must reach the corresponding minimum sound pressure level.
- Reversing test:
  - Have a minimum sound pressure level according to Figure 1 at a 6 km/h car's reversing speed.
- Frequency change:
  - At least one tone of one of the frequency bands must vary with a minimum speed of 0.8% per km/h in the speed range from 5 km/h to 20 km/h. At least one band should meet the requirements.
- The maximum level of acoustic pressure obtained at a distance of 2 m from the front plane of the vehicle is 75 dB (A).

Frequency in Hz		Constant Speed Test paragraph 3.3.2 (10 km/h)	Constant Speed Test paragraph 3.3.2 (20 km/h)	Reversing Test paragraph 3.3.3
Column 1	Column 2	Column 3	Column 4	Column 5
Overall		50	56	47
1/3rd Octave Bands	160	45	50	
	200	44	49	
	250	43	48	
	315	44	49	
	400	45	50	
	500	45	50	
	630	46	51	
	800	46	51	
	1 000	46	51	
	1 250	46	51	
	1 600	44	49	
	2 000	42	47	
	2 500	39	44	
	3 150	36	41	
	4 000	34	39	
	5 000	31	36	

Figure 1. Minimum Sound Level Requirements, from UNECE 138 [2].

The frequency change test is used to simulate the traditional sound effect of speed variation of a combustion vehicle. Reference test is developed at 5 km/h, being those at 10, 15 and 20 km/h used to make comparison. Furthermore, the maximum level of acoustic pressure is used to avoid noise pollution.

3. MAVAS MODEL

3.1 Acoustic Model Used

The mathematical model used [8] generates the noise produced by the impact of a pair of gear teeth belonging to a pair of free dry spur gears. The sound of the complete gear is simulated as a successive composition of the teeth clash.

The model used was constructed by adapting the algorithm [9] which determines the sound pressure produced by a pair of lubricated cylindrical spur gears. In summary, that model provides the sound produced by the clash of a pair of teeth equating it to the clash of two cylinders. Then, the sound is replicated for every hit during the gear cycle.

The equations of the sound pressure produced by the clash of two cylinders can be found at [10]. The sound pressure depends on the impact speed of the cylinders and their physical properties.

3.2 Proposed Solution

MAVAS is designed to have a mechanical assembly as simple as possible, thus the sound is produced by gears without lubrication. To achieve a more complex mechanical sound three pairs of gears were proposed. In this paper, a first assembly has been designed selecting three gear pairs that have the same distance between centres.

The gear pinions are mounted on the same driver shaft while the gear crowns are mounted aligned on bearings. The bearings make the gear pairs turn free and reduce the load as much as possible. The assembly is wrapped into a box with a horn-shaped opening to direct the sound as it is shown in Figure 2.

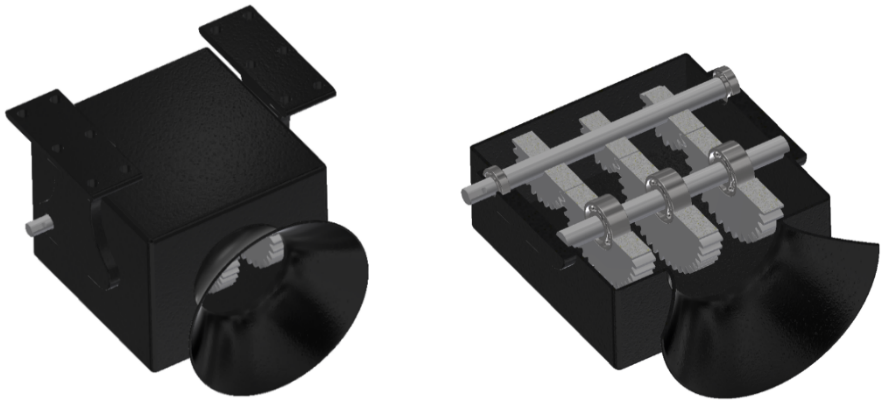

Figure 2. MAVAS sketch.

The sound produced by the gears changes due to the size and number of teeth. The geometric characteristics selected for this study are shown in Table 1:

Table 1. Gears selection.

Gear Pair	Module	Nº of Teeth	
		Pinion	Crown
1	5 mm	24	36
2	6 mm	17	33
3	5 mm	18	42

Finally, the angular speed of the driver shaft should be determined considering the speed of the vehicle. To achieve the desired mechanical sound, the gear pinions rotate at 2 Hz when the vehicle moves at 5 km/h and the angular speed increases proportionally up to 8 Hz when the vehicle moves at 20 km/h.

4. RESULTS

The acoustic model was executed under the conditions described above to calculate the sound pressure emitted at a distance of 2 m, considering that MAVAS is at half of the length of the vehicle. This simulates similar conditions to those at the regulation with the vehicle stopped. Indeed, the sound is recorded in the front or rear plane of the vehicle.

Sound pressure levels provided by the model can be compared with the restrictions of the regulation. Table 2 shows the overall sound pressure level for the required speeds.

Table 2. Overall sound pressure level at a certain speed.

Pinion's Angular Speed	Car's Associated Speed	Overall Sound Pressure Level
2 Hz	5 km/h	63,52 dB (A)
4 Hz	10 km/h	67,75 dB (A)
6 Hz	15 km/h	69,75 dB (A)
8 Hz	20 km/h	70,72 dB (A)
2,4 Hz	6 km/h (reversing)	64,48 dB (A)

Only the overall sound pressure level at 10 and 20 km/h (in blue) are required for the forward test, showing SPL higher than what is established in Table 1. Also, under reversing conditions (in red) results have an appropriated overall sound pressure level. Any overall pressure level exceeds the maximum of 75 dB (A).

To complete what is requested in the forward test, it is necessary to analyse the third band spectrum, Figure 3.

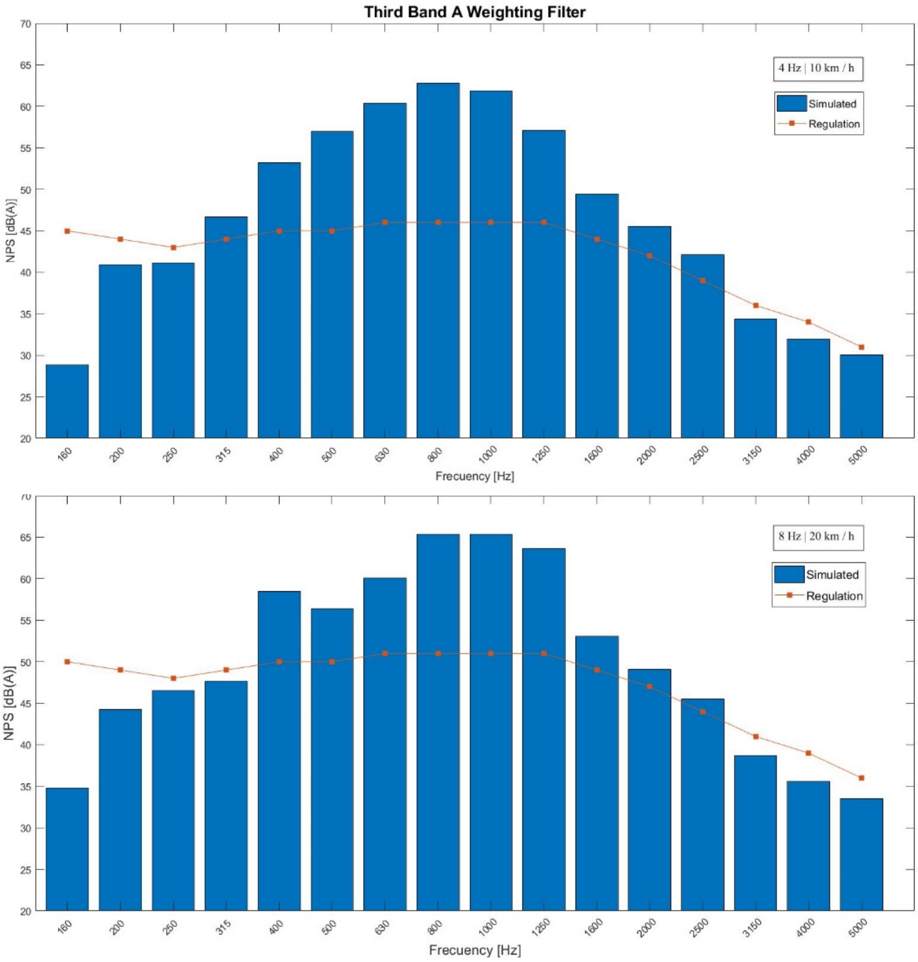

Figure 3. Third Band Spectrum at 10 km/h and 20 km/h.

Only two frequency bands needed to exceed the minimum requirements. At 10 km/h bands from 250 to 2500 Hz agree the requirements and at 20 km/h bands from 400 to 2500 are also in consonance.

To determine compliance with the requirements of the frequency change test, the frequency spectrum of the signals at the four study speeds have been compared. Figure 4 shows the full range of the spectra that was extended at the third octave band of 1000 Hz. On these graphs, the change of one of the peak frequencies was signalled. This peak varies main frequency with an average of 1% per km/h, higher than the 0.8% demanded by the regulation.

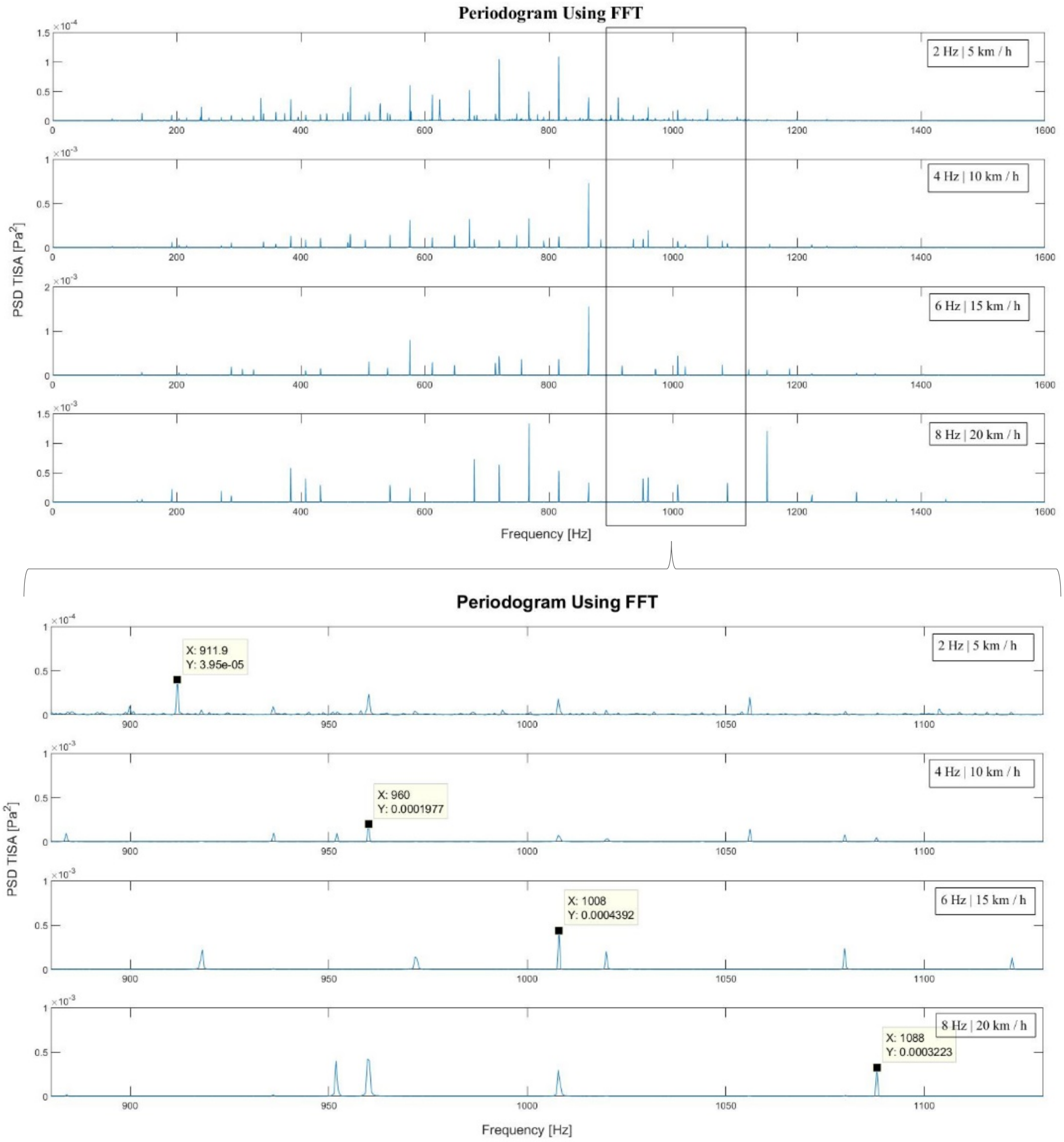

Figure 4. Frequency Spectrum at 5, 10, 15 and 20 km/h extended at 1000 Hz third band.

5. CONCLUSIONS

The use of a Mechanical Acoustic Vehicle Alerting System produces a sound pressure level that allows what is determined on the regulation, being viable as an alternative to current AVAS.

The construction of a MAVAS described in this paper is a simple mechanical solution that can improve the perception and detectability of quiet vehicles. A proper assembly of the system in the vehicle is presented as a new research path challenge. Designing the mechanical drive of the gears without complicating or expensive the product is also an achievement. This will make MAVAS competitive in front of electronic AVAS.

Currently, progress is being done on the creation of a set-up of a free pair of gears driven by an electric motor, see Figure 5, to validate the acoustic results and detail the limits of the acoustic model.

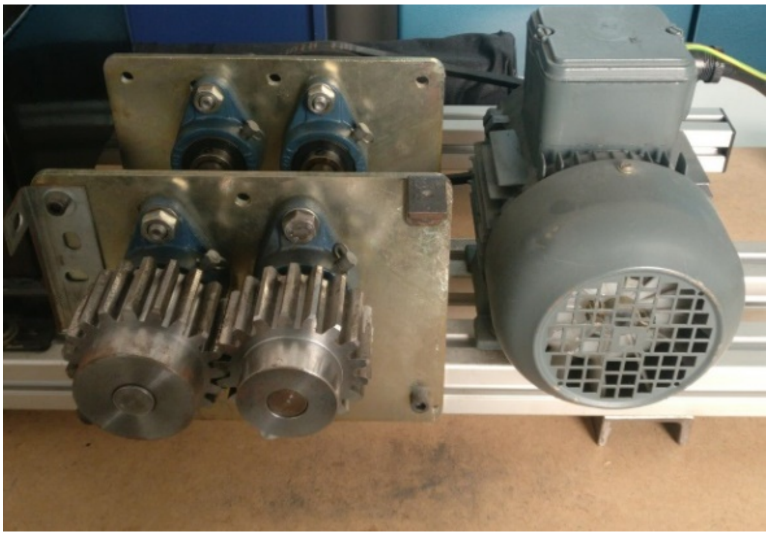

Figure 5. First experimental gears set-up.

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