Improvements in noise mitigation of a postal delivery service: a comparison among hybrid, electric and conventional vehicles

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ABSTRACT

As urbanization increases, best practice of sustainable mobility is needed to improve environmental quality in city centres. Postal companies have a significant role regarding the reduction of road traffic noise and air pollution in urban areas. In order to mitigate environmental impact, Italian postmen conventional motorcycles are being replaced with silent ecological safe four-wheel vehicles, able to easily move in limited traffic zones to deliver mail at a city level.
Methodologies recommended by EU regulations were applied and acoustic measurements were carried out to assess sound pressure levels due to single vehicle passages for different road and working conditions. Noise contributions of a hybrid quadricycle were measured and they were compared with the acoustic performances of a traditional two-wheel motorcycle and an electric four-wheel vehicle. As a result of frequency response analysis, noise due to electric and hybrid vehicles differs considerably from the one due to a combustion engine motorcycle.

1. INTRODUCTION

Transport sector has to satisfy a growing demand for mobility and at the same time it must find solutions to reduce negative external costs, which affect society (health, safety and security), economy (congestion) and environment (pollution and CO_2 emissions as well as noise).
Regarding social and economic aspects, transport is the highest budget item after house-related expenditures (housing, electricity, water and gas)[1]. Trends in transport, particularly as concerns freight, follow economic developments and in periods of recession they demonstrate to recover more quickly than the rest of economy[2]. The share of logistics in Europe is estimated close to 14% of GDP (Gross Domestic Product)[3]. While GDP (at constant 1995 prices) grew at an

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average yearly rate of 2.4% from 1995 to 2006, freight transport performance (in ton-kilometres) increased of 2.8% yearly[4]. Road plays a predominant role in EU-27 transport, regarding both passengers and goods: it accounts for the largest share of total freight transport performance (about 46%). In 2006, road transport was the mode that carried most goods (89% of load tons, 77% of ton-kilometres), that consumed most energy (26% of EU-27 total final energy consumption) and that emitted most greenhouse gases (93% of transport total GHGs)[4].
In spite of enhancements in vehicle efficiency, transport emissions raise because of the development of traffic volumes and the shift of mobility towards road mode[5]. As concerns environmental impact coming from constant transport increase, improvements are being obtained by means of growing shares of lead-free and sulphur-free cleaner fuels, reduced emissions of ozone precursors and particulate matter, standards for new vehicles to produce fewer CO_2 emissions per vehicle-kilometre. Another effective solution consists in fuel shift towards electric, hybrid and bio-fuel vehicles. Green Post project aims at reducing environmental impact of delivery services through electric and hybrid quadricycles. Project is co-ordinated by Italian leader in mail delivery (Poste Italiane) and it is financed by EU in the context of IEE program (Intelligent Energy for Europe): in July 2008 it has been inserted in the SEE campaign (Sustainable Energy Europe) promoted by the European Commission. Activities provide the experimentation of 57 quadricycles, equipped with electric or hybrid engine, to deliver mail in the historical centre of Perugia (Umbria, Italy). Perugia was selected as optimal test site to analyse performances of vehicles in hard conditions, concerning thermal stress due to variability of climate and weather conditions as well as mechanical stress due to altimetry trend of city and to stone paving of most centre streets. Experimentation provides monitoring of performances and development of vehicles which can contribute to save energy saving as well as to reduce noise and air pollution also in other urban areas.

2. STANDARD REFERENCES

In order to have consistent and comparable results, noise measurements on hybrid quadricycle were carried out according to the same standards already used for conventional and electric vehicles in previous tests[6]. Vehicles obtained certificates of component type-approval regarding noise pollution and documents fitting free movement and free placing on market; however, as a reference to assess acoustic performance, noise measurements were carried out according to standard procedure for vehicle testing during approval.
Directive 97/24/EC[7] of the European Parliament and of the Council of 17 June 1997, concerning certain components and characteristics of two or three-wheel motor vehicles, applies to permissible sound level and exhaust systems too. It describes measuring conditions and methods: as concerns noise, tests are provided both for vehicles in motion and for stationary vehicles.
In order to test motor vehicles having at least four wheels, with particular regard to their noise emissions, similar measurement methodology is described in Regulation n. 51[8] of the Economic Commission for Europe of the United Nations (UN/ECE).

3. VEHICLES

Sustainable delivery vehicle under test was Ducati Energia Free Duck. It is a light city quadricycle and it is available in 2 versions:

1. electric zero emission vehicle (ZEV);
2. hybrid emission vehicle (HEV, Figure 1).

Figure 1: Hybrid four-wheel motor vehicle.

Quadricycle general construction features are:

- electric traction with direct transmission on wheels by 2 DC Brushless technology engines of 2 kW each (electric engines are positioned into the rear wheels);
- 4 hydraulic disk brakes;
- electrical welding steel chassis with ABS shock-proofed body;
- 90 kg payload having about 180 litre volume.

Serial hybrid technology joins the electric motors, driving the vehicle, with a small capacity endothermic engine (100 cm^3, single cylinder, 4 strokes, petrol engine), which works only as a generator in order to recharge battery (8 lead-acid cells, 12 V, 42 Ah).
Electric vehicle has an autonomy of about 50 km, whereas hybrid vehicle can expand its autonomy to over 200 km, due to a 5 litre fuel tank. Maximum speed is declared about 45 km/h: during road tests, quadricycles performed 35 km/h.
Electric Free Duck was already tested[6]; noise measurements on hybrid Free Duck are reported in present paper. Conventional vehicle examined in previous tests[6] was a Piaggio Liberty 125 motorcycle (125 cm^3, single cylinder, 2 valves, 2 strokes, automatic twist and go transmission.

4. MEASUREMENT INSTRUMENTS

Noise measurements were carried out using a precision sound-level meter 01dB Solo, meeting requirements of Class 1 instruments, in compliance with IEC standards. Measurement system was calibrated by means of a sound calibrator that fulfils requirements of precision Class 1 according to IEC standards. Difference between readings at the beginning and at the end of measurement session was less than 0.5 dB and obtained results were accepted.
Vehicle speed was measured and checked compatibly with the accuracy of vehicle instruments.
Meteorological instrumentation used to monitor environmental conditions included measuring devices for temperature, wind speed and direction, barometric pressure and relative humidity.

5. MEASUREMENT CONDITIONS

A. Test site

All noise measurements on different tested vehicles were carried out in the same site[6], in a suburban area of Perugia free of significant acoustic disturbances.

Test site consisted of a central acceleration section surrounded by a substantially flat test area. Acceleration section was level, track surface was dry and rolling noise was low. Test track paving in dense asphaltic concrete respected required physical specifications: surface was as homogenous as possible within the test area.
Site surface was in accordance with requirements given in regulations[7,8]. There was no obstacle to affect sound field close to microphone and sound source: observers carrying out measurements positioned themselves as not to affect measuring instrument readings.

B. Weather and Environmental Conditions

Tests on hybrid quadricycle were made on 8th June 2009 under favourable weather conditions.
Results were not affected by wind, whose speed at microphone height didn't exceed 5 m/s during tests; however microphone was provided with recommended windscreen.
Difference between background noise and measured noise was at least 10 dB and it was often higher than 16 dB: readings were only rounded off to the nearest 0.5 dB disregarding any other correction, differently from what provided by regulations[7,8], as the purpose of present study is a characterization of noise performances rather than an assessment of vehicle approval.

C. Vehicle Conditions

Before starting measurements, hybrid quadricycle was brought to normal operating conditions, as already done with conventional and electric vehicles[6]. During tests vehicle was in running order and tyres corresponded to requirements. Measurements were made on unladen vehicle, as in previous tests[6], in order to compare noise performances in critical conditions of higher speed.

6. MEASUREMENT METHOD

A. Measurement Nature

Noise produced by hybrid vehicle was measured using "A" frequency weighting and "Fast" time response according to methods described in regulations[8] for vehicle in motion and vehicle when stationary. At any transit of tested vehicle maximum sound pressure level L_{AFmax} and Single Event Level SEL were measured, both expressed in dB(A). All tests on hybrid quadricycle were carried out while endothermic engine was working: stationary vehicle measurements provided a reference value to be compared with exhaust system noise of traditional motorcycle, whereas, in the case of just electric vehicle, noise was inevitably measured just in motion[6].

B. Measurement of Noise from Vehicle in Motion

As in previous tests[6], at least two measurements were made on each side of vehicle[8]. Microphone was positioned at a distance of 7.5 m from CC' reference line (Figure 2) of track and 1.2 m above ground. Maximum sensitivity axis (PP' line) was horizontal and perpendicular to vehicle path (CC' line). Two lines, AA' and BB', were marked out on test runway parallel to PP' line, respectively 10 m forward and 10 m rearward. Maximum sound pressure level was measured when vehicle was driven between lines AA' and BB', as close as possible to CC' line. All tested vehicles were equipped with automatic transmission, without manual selector, and they approached AA' line at uniform speeds: hybrid quadricycle was driven up to a maximum on-road speed of 35 km/h, as for electric vehicle[6]. When the front of vehicle reached AA' line, throttle was fully opened as rapidly as possible and it was being held in fully-opened position until the rear of vehicle crossed BB' line; then throttle was closed again quickly.

Measured noise emissions were valid as the difference between consecutive measurements on the same side wasn't higher than 2 dB. Recorded values correspond to the highest noise levels[8].

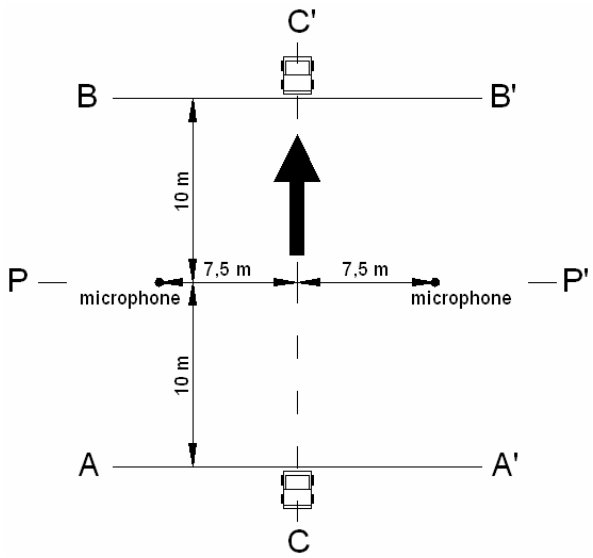

Figure 2: Measuring positions for vehicle in motion.

C. Noise from Stationary Vehicle: Exhaust System

According to regulations[8] and previous tests on conventional motorcycle[6], three measurements of maximum sound pressure level L_{AFmax} were carried out concerning fuel engine of stationary hybrid vehicle. Microphone was positioned level with exhaust outlet, at a distance of 0.5 m from it. Microphone maximum sensitivity axis was parallel to track surface (at least 0.2 m above it) at an angle of 45° to vertical plane of exhaust emission direction (Figure 3).

Sound level was measured when a constant endothermic engine speed was reached, being it independent of throttle position in the case of hybrid vehicle. Maximum sound-level meter reading was taken as measurement value and the highest value among three measurements (less than 2 dB differences) was test result.

Figure 3: Microphone position during exhaust system noise measurements (stationary hybrid vehicle).

D. SEL Measurements

Finally also tests on hybrid four-wheel vehicle were integrated with Single Event Level measurements (SEL), to assess and compare specific contribution of noise emitted by vehicle during its transit. Tests were carried out with working fuel engine, both on level road and gradient road (Figure 4), as for traditional motorcycle and electric quadricycle.

Figure 4: Microphone position during SEL measurements on gradient road (hybrid vehicle in motion).

7. MEASUREMENT RESULTS

Results coming from noise tests on hybrid vehicle are reported in present paper. Figures 5 to 8 show frequency analysis and time history of the most significant measurements carried out on unladen four-wheel vehicle while endothermic engine was working.

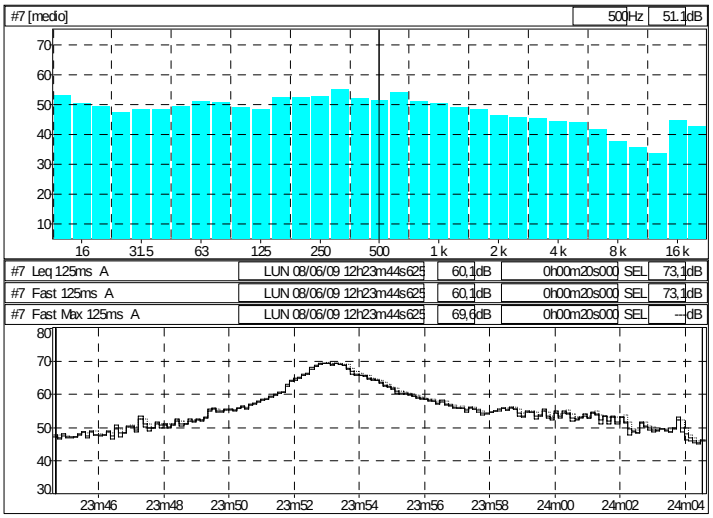

Figure 5: Hybrid four-wheel vehicle – Speed of 35 km/h (left side, 1st measurement).

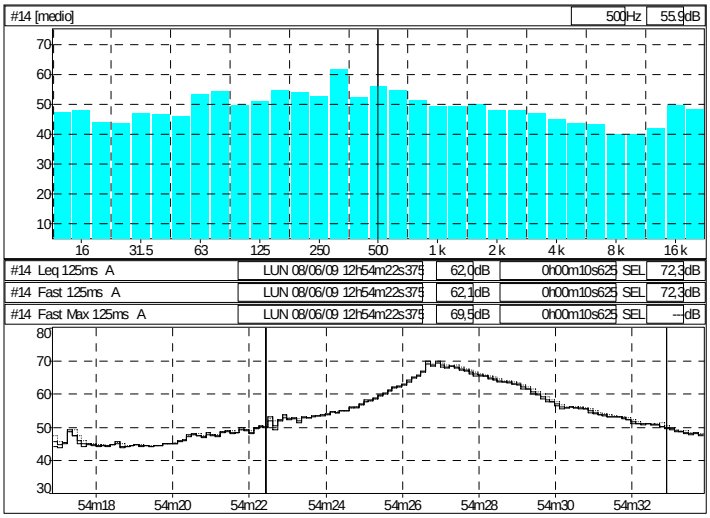

Figure 6: Hybrid four-wheel vehicle – SEL on gradient road (right side).

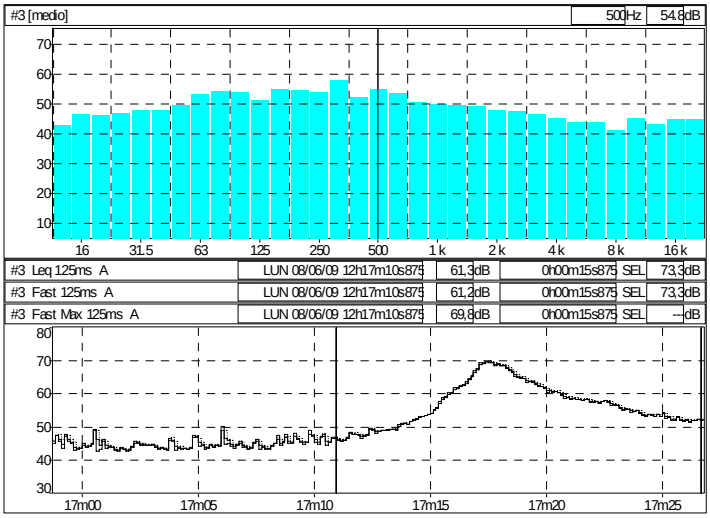

Figure 7: Hybrid four-wheel vehicle – SEL on level road (right side).

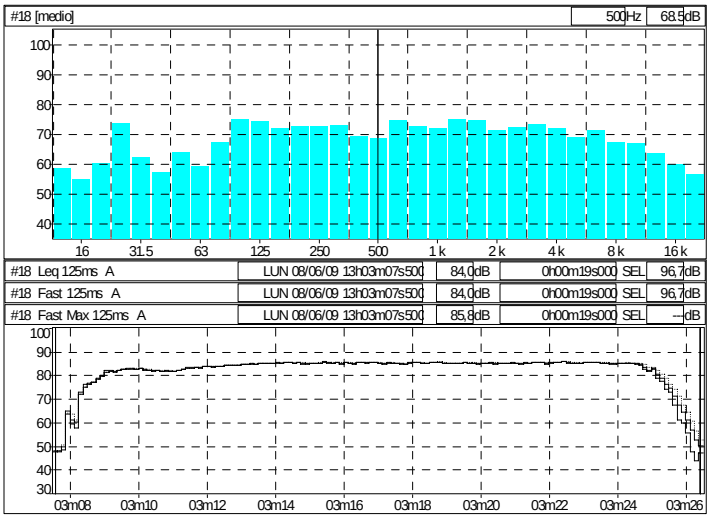

Figure 8: Hybrid four-wheel vehicle – Exhaust system noise (3rd measurement).

Table 1 resumes obtained results concerning hybrid quadricycle and Table 2 shows a comparison among all tested vehicles.

Table 1: Hybrid four-wheel vehicle – Noise measurement results

Condition		Parameter [dB(A)]		Hybrid four-wheel
Background		L_{AFmax}	*(dB(A))*	55.0 (54.8)
Vehicle in motion	*35 km/h, right side*	L_{AFmax}	*(dB(A))*	68.5 (68.5)
		L_{AFmax}	*(dB(A))*	69.0 (69.2)
	35 km/h, left side	L_{AFmax}	*(dB(A))*	69.5 (69.6)
		L_{AFmax}	*(dB(A))*	69.5 (69.3)
	35 km/h final result	$\boldsymbol{L_{AFmax}}$	***(dB(A))***	**69.5**
	Gradient road	***SEL***	***(dB(A))***	**72.5 (72.3)**
	Level road	***SEL***	***(dB(A))***	**73.5 (73.3)**
Stationary vehicle	*Exhaust*	L_{AFmax}	*(dB(A))*	85.0 (85.2)
		L_{AFmax}	*(dB(A))*	85.0 (84.9)
		L_{AFmax}	*(dB(A))*	86.0 (85.8)
	Exhaust final result	$\boldsymbol{L_{AFmax}}$	***(dB(A))***	**86.0**

Table 2: Comparison among traditional, electric and hybrid vehicles – Noise measurement results

Condition	Parameter [dB(A)]		Traditional two-wheel	Electric four-wheel	Hybrid four-wheel
Background	L_{AFmax}	*(dB(A))*	51.5	43.5	55.0
30 km/h	L_{AFmax}	*(dB(A))*	78.5	65.0	–
35 km/h	L_{AFmax}	*(dB(A))*	–	66.5	69.5
35 km/h	L_{Aeq}	*(dB(A))*	–	56.5	60.0
40 km/h	L_{AFmax}	*(dB(A))*	80.0	–	–
50 km/h	L_{AFmax}	*(dB(A))*	81.0	–	–
Gradient road	*SEL*	*(dB(A))*	79.5	67.0	72.5
Gradient road	*SEL*	*(dB(A))*	79.5	67.0	73.5
Exhaust	L_{AFmax}	*(dB(A))*	103.0	–	86.0

8. CONCLUSIONS

Green Post project is planned as an exchange of best practices and lessons learned in postal delivery with electric and hybrid vehicles. Overall effects due to the substitution of a traditional petrol fleet with alternative green light quadricycles need to be properly analysed from a social, economic and environmental perspective in order to be largely implemented.

Substitution of mail delivery vehicles aims at improving energy efficiency and safety for operators, at reducing fuel consumption, CO_2 emission, air pollution and noise, at stimulating replication of similar initiatives.
As concerns noise, experimentation on electric and conventional vehicles began on 2008: the present paper shows test results concerning sound pressure levels produced by a light hybrid quadricycle, provided with electric motors supplying traction and an endothermic engine to recharge batteries.
Result analysis shows that maximum noise level L_{AFmax} produced by hybrid vehicle is higher than the one coming from electric version in the same conditions (+3.0 dB at a speed of 35 km/h), due to contribution of endothermic engine. Equivalent continuous sound pressure level L_{Aeq} at 35 km/h increases of about 3.5 dB: at present, endothermic engine is equipped with constant rpm, but as its future development could provide performances depending on battery charge conditions, by comparing noise due to hybrid and electric vehicles resulting L_{Aeq} would be about 57.5 dB(A) if endothermic engine worked at 25% on hybrid quadricycle (only 1.0 dB higher than electric vehicle noise).
However, hybrid quadricycle guarantees longer autonomy range than just electric model.
Instead of higher contribution of rolling noise, because of four wheels, hybrid and electric vehicles generate very lower sound pressure levels than the ones produced by two-wheel conventional motorcycle. SEL measurements, in gradient and level road conditions, confirm results.
Acoustic performance of hybrid vehicle is slightly worse on left side, where exhaust outlet is positioned: maximum difference between two sides of tested quadricycle was 1.0 dB. Noise emissions from hybrid quadricycle exhaust outlet are still much lower than the ones generated by traditional two-wheel vehicle (86.0 dB(A)instead of 103.0 dB(A)).
Comparison of acoustic performances shows that the substitution of traditional delivery related vehicles with electric and hybrid quadricycles significantly contribute to reduce noise pollution.
Tested four-wheel vehicles are also compatible with future developments concerning the use of alternative fuels and new technologies (hydrogen fuel cells).

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