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Spazia-HPP: Hybrid plug-in for small vehicle

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Abstract

The Spazia-HPP project proposes a conversion kit called Hybrid Power Pack (HPP) [5] for common microcar; it was installed on a prototype called "Spazia", a typical quadricycle of the category L6e. It has an internal combustion engine, which allows you to turn common microcar into parallel hybrid thermal – electric vehicle.

The aim is to promote a system of easy installation, which increase acceleration by 20% and reduces fuel consumption by almost 25% compared to a traditional Diesel quadricycle. The results are obtained by testing on a chassis dynamometer at the research centre ENEA Casaccia (Rome).

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1. Introduction

Transport is responsible for 35% of world consumption of oil, of which 60% is attributable to road transport.

EU legislation implemented EURO-VI and antecedents [2]. Italian legislation, in accordance with the "Directive 83/2012" promotes a three-year plan of incentives for the purchase of eco-friendly cars, including electric vehicles and hybrids.

The current market offers some solutions of pure electric vehicles for the category of microcar, no solution for the hybrid drive.

The HPP kit can be installed on the quadricycle member of category L6e and L7e mounting a diesel (ICE) and CVT transmission, without any structural change in the engine compartment and without making any changes to your system as standard. In Spazia-HPP project the kit has been installed on the prototype "Spazia" (Figure 1), thus obtaining a parallel hybrid vehicle "plug-in"; the traction battery can be recharged in less than two hours with a common outlet by 3 kW. The vehicle has two seats and a total weight of 550 kg.

Figure 1 Spazia prototype show at Smart Camp event in Rome (2014 July)

The tests on a chassis dynamometer for the characterization of consumption have been made on the traditional system driven by the internal combustion engine, on traction in pure-electric mode and on hybrid system.

The driving cycles chosen for the simulations are the ECE 15 and the ECC cycle designed to test the best line of electric drive installed on the prototype.

This project wasn’t designed for a fully electric vehicle, then the maximum performance in electric mode can’t be compared to a traditional quadricycle and it was necessary to adopt an “ad hoc” driving cycle.

The study and implementation has been carried out jointly by the research centre ENEA Casaccia (Rome) and the CTL - Research Centre for Transportation and Logistics at the University of Rome La Sapienza.

Further developments will be made adopting an advanced logic for the automatic management of the request load to both engines, for the recovery of electricity during braking and for the automation of the start and stop function.

This article is divided into five sections: this introduction, the configuration of the powertrain with testing on a chassis dynamometer at ENEA, the preliminary results, the economic valuation, further developments and conclusions.

Nomenclature

BMS	Battery Management System
CVT	Continuously Variable Transmission
ECE 15	European Standard Elementary Cycle
ECU	Electronic Control Unit
ENEA	National Agency for Energy and Environment
ECC	Enea Electric Cycle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
HPP	Hybrid Power Pack
ICE	Internal Combustion Engine
EOBD	Standard diagnostic protocol
RPM	Revolutions Per Minute

2. Powertrain configuration and test on chassis dynamometer of ENEA Casaccia research centre.

The engine chosen for this project is manufactured by Lombardini and together with the CVT produced by CVTech-IBC equips near all the microcar market [7]. The added electric traction system is composed by electric motor 2.2 kW by Perm Motors, controlled by a Sevcon inverter, and an energy storage system by 40 Ah in forty-eight Li-Ion (24s2p) cells provided by EIG (Table 1), controlled in voltage and temperature by a BMS. This also manages the charging plug-in phase. In Figure 2 you can see the kit installed on the secondary pulley of the CVT. Table 2 and Table 3 show respectively data specs of the electric motor and diesel engine.

Table 1 Battery pack specifications

	Characteristic	Value
Single - Cell	Nominal Voltage [V]	3.6
	Minimum Voltage [V]	3
	Maximum Voltage [V]	4.15
	Capacity [Ah]	20
Pack - 24 s 2p	Nominal Voltage [V]	86.4
	Minimum Voltage [V]	72
	Maximum Voltage [V]	99.6
	Nominal Power [W]	3456

Table 2 Electric motor specifications

Characteristic	Value	Note
RPM range	From 0 to 6000	Depending on the windings
Nominal power	3 kW	Depending on voltage
Torque	7.6 Nm	For RPM < 1800
Overload	~ 24 Nm	For less than 0,5 Sec. at RPM < 50
Weight	~ 5,8 KG	Including encoder
Voltage	24 V	

Table 3. ICE specifications

Characteristic	Value
Type	Diesel - 4T
Cylinders	2
Displacement	440 cm^3 Bore & Stroke 68×60.6 mm
Injection	Common Rail
Weight	48.5 kg
Max Power	8.5 kW
Max revolution speed	4400 RPM
Max Torque @ 2000 RPM	21 Nm
Max fuel specific consumption at max power	320 g/kWh

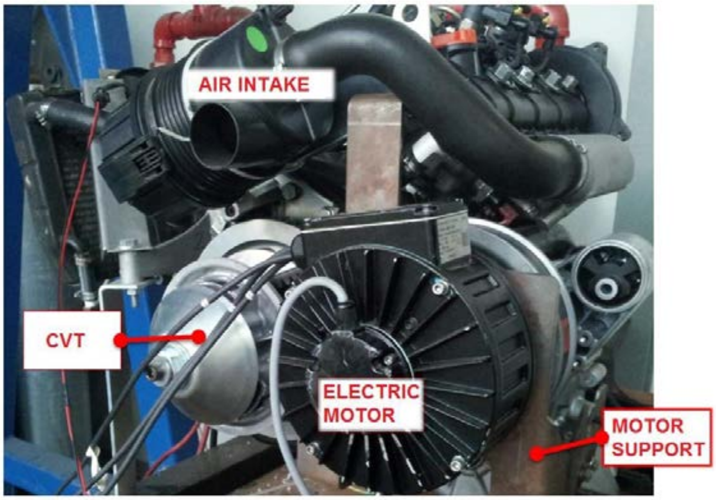

Figure 2. Engine with CVT transmission

To obtain greater management flexibility for both engines, the same accelerator pedal provided by Lombardini and installed on the standard vehicle has been used to give load signal to diesel and electric motors. In this way both motors receive the same load percentage request.

In anticipation of a more advanced logic it was installed a switch to manually control the shut down and turn on of Diesel engine like a Start & Stop function.

The final scheme of the hybrid power train is shown in Figure 3.

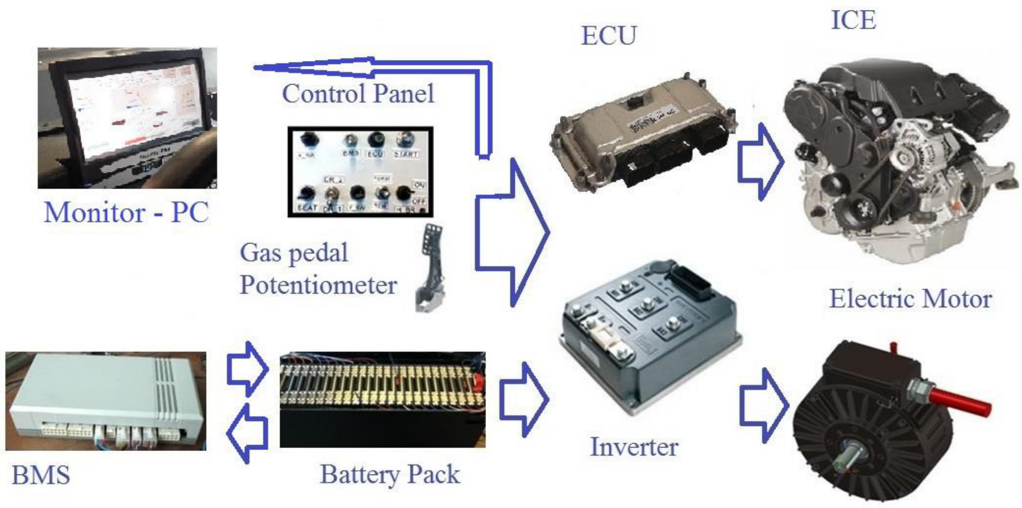

Figure 3. Powertrain scheme

The tests were divided into three phases for each of the operating modes available, evaluating consumption and performance in each one:

1) Electric
2) Diesel
3) Hybrid

The driving cycle used (Table 4) for tests at point 1) is purpose-built in the laboratory to observe what are the performance of the vehicle; for tests at points 2) and 3) it has been used the driving cycle ECE 15 [2]. Tests show comparison between the required power from both engines in all the tests made: the performance in terms of maximum speed, maximum acceleration and range of the batteries and the fuel tank.

Table 4 driving cycles

	ECC	ECE 15
Distance (m)	1000	994.6
Time (s)	842	195
Standing time (%)	60 %	23%
Braking time (%)	5 %	20%
Max Speed (m/s)	8.33 m/s	12.5 m/s
Average Speed (m/s)	5.55 m/s	5.1 m/s
Max acceleration (m/s^2)	0.78 m/s2	1.4 m/s^2

3. Preliminary results

In are shown performance in each traction mode available:

Table 5. Performance's comparison

	Max. Acceleration	Max. Speed	Consumption	Range
Diesel	2.7 m/s^2	15 m/s	0.13 kWh/km (3.0 l/100 km)	250 km with 8.5 l fuel tank
Electric	0.7 m/s^2	10.5 m/s	0.10 kWh/km (2.5 l/100 km equivalent)	25 km with a fully charged battery (Li-ion 40 Ah, 86 V)
Hybrid	3.4 m/s^2	18 m/s	0.11 kWh/km (2.6 l/100 km *)	386 km

* The consumption is the sum of oil diesel engine plus the equivalent of energy consumed by electric motor.

For all modes they have been reported graphs with power and speed (within the acceptable tolerance) on the cycles, made with a man onboard driving the prototype on the dynamometer chassis.

1) Electric traction mode

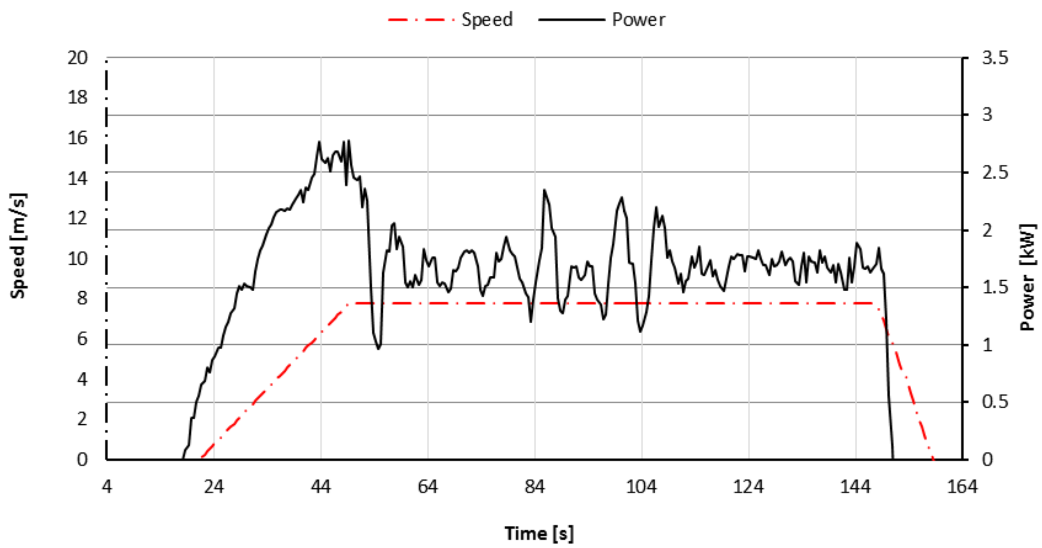

Figure 4 Electric mode - ECC Driving Cycle

2) Diesel traction mode

The driving cycle used for this simulation is ECE15 (Figure 5).

The fuel is supplied directly from the ECU of the manufacturer Lombardini and accessible with the EOBD protocol. It was quantified in an average value of 2.94 litres per 100 km.

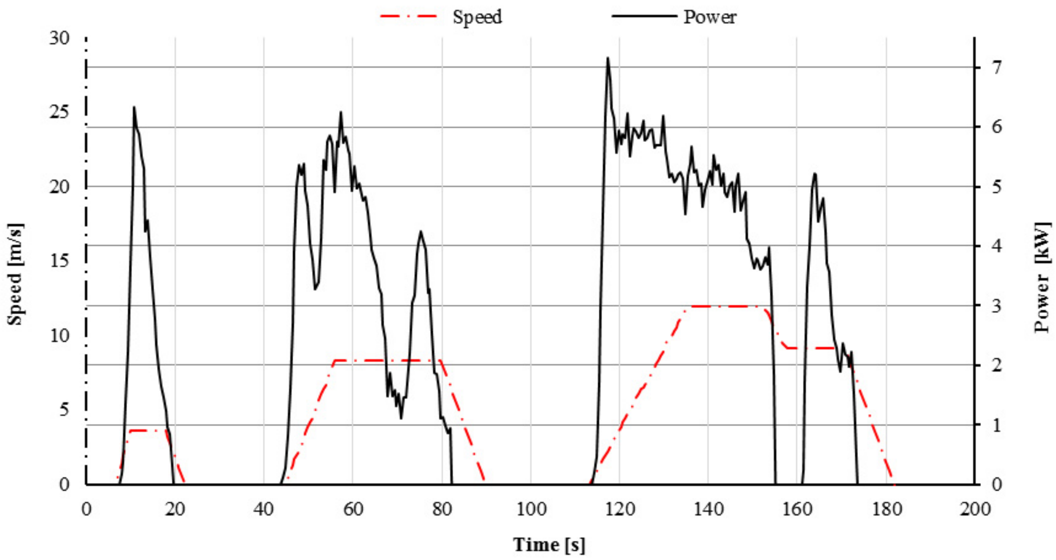

Figure 5. Diesel mode - ECE 15 driving cycle

3) Hybrid traction mode

This traction mode was performed using both engines as propulsion.

The configuration adopted requires the use of both motors in all stages of the gear, without any management logic.

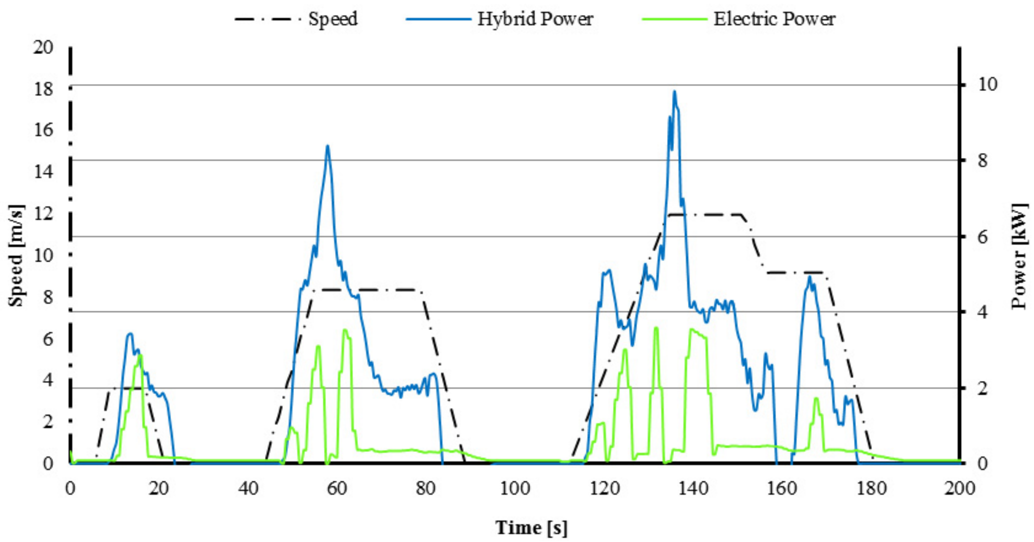

Table 6 Hybrid Mode, ECE 15 driving cycle

4. Economic evaluation

The realization costs of this prototype was around 5000 €; a larger production would lead to a decrease in it. The battery pack installed is 50% of the total costs and it's oversized if you plan to mainly use the vehicle as a hybrid one. In this case it is possible to install a more little battery pack [6].

For example if you wanted to maintain a range in hybrid mode comparable to that in ICE , then you could install a 10 Ah battery with HPP kit, it will cost down to 2500 € obtaining range in pure electric mode of about 7 km.

The actual cost per 100 kilometre of the prototype is shown in Table 7:

Table 7. Actual Cost

	Diesel	Hybrid	Electric
Cost € per 100km	5.2	4.1	2.2

Cost are obtained on simulated driving cycle ECE 15 for hybrid and diesel mode, while on ECC cycle for Electric only. Prices are calculated on the basis of the payments up to date to the third quarter of 2014 according to the Italian Authority for electricity [4] and the Ministry of economic development [3]: diesel 1.7 € / l. electricity 0.2 € / kWh.

5. Further developments and conclusions.

The Spazia-HPP project will be followed by other projects with the same prototype on which other functions will be implemented: regenerative braking (kinetic energy recovery), start and stop automated, optimized management of motor load, measurement of vehicle emissions.

The choice to use the same accelerator pedal to manage both engines without introducing a control unit for the management logic causes the same load demand for both engines, and this is an advantages for ease of installation and reduced costs.

Instead of this, the ideal condition would be to have management logic of the load demand with the aim to optimize the range of work for battery and to reduce even more the fuel consumption in hybrid mode.

Comparing the three modes it is seen that this type of installation does not allow an intensive pure electric use, but is very beneficial when electric is used in conjunction with the heat engine.

The benefits of using this system in hybrid mode than the traditional system are:

- Reduction in consumption of 25% are referred to the ECE 15 cycle, for a consideration of € 0.40 saved for every litre of fuel; thinking about a yearly average mileage 10000 km / year savings in the cost of 140 € / year.
- Increase of 20% of the maximum acceleration from 2.7 m/s^2 to 3.4 m/s^2;
- Reduction of emissions (not quantified at this early stage);
- Using the dual modes of traction;
- Charging Plug-in charger on board.

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