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HYBRID POWER UNIT DEVELOPMENT FOR FIAT MULTIPLA VEHICLE

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ABSTRACT

In the "scenario" of increasing concerns for environmental pollution, hybrid vehicles will play a significant role in the near future. Compared to electric vehicles, the hybrid ones have an unrestricted driving range, higher performance and transport capability, still fulfilling ZEV emission regulation.

The hybrid vehicle features a power train that integrates a thermal engine with an electric motor. Among the several possible configurations for hybrid vehicle, the parallel hybrid one has been chosen for the FIAT MULTIPLA, for the following reasons:

- lower weight and volume of the electric unit to obtain the same driving mission;
- higher global efficiency of the system, due to direct thermal to mechanical energy conversion;
- a better vehicle performance (acceleration and max speed), thanks to the contribution of both motors to traction.

In the development of a hybrid parallel concept, the critical aspects to be overcome are related to the system mechanical complexity and the simultaneous control of the two motors.

In this paper the Fiat Auto and Elasis approach to the hybrid vehicle is presented with particular reference to the powertrain unit and its control strategies.

INTRODUCTION

In the last years the European legislation and environmental issues have focused the attention to the inconvenience produced by traffic density in our most congested European urban centers. Electric vehicles, as reported by several studies performed in different European cities, could substitute less than 10 % of the vehicles in circulation in the cities, provided that they can assure a real range of more than 80 km. On the contrary hybrid vehicle would allow a substitution of a bigger portion of the vehicle city park, thanks to their "range extension" and "peak performance" features.

The hybrid vehicle seems to be a very promising answer to today's different demands such as:

- free driving in emission protected zones
- ability to match different condition in urban or extra urban driving
- unrestricted range and transport capabilities like thermal vehicles
- same or similar driving characteristics as a conventional vehicle
- reduced dependency on batteries
- use of existing infrastructure
- commercially interesting image.

The mass production feasibility of the electric vehicle remains nowadays a big concern, primarily because of the battery problems. In case of the hybrid vehicle, battery dependency is reduced and so the hybrid vehicle is more acceptable to the public.

Conventional vehicles, especially those equipped with gasoline engines, have lower fuel economy and higher emissions especially in short range distance driving during warm-up phases, but offer high performance, long distance and high transportation capability.

Although hybrid vehicles suffer from a higher weight if compared to conventional internal combustion driven and pure electric vehicles, they may offer a possibility of satisfying personal and commercial needs with lower emissions and higher global efficiency.

On the other hand hybrid vehicles have higher complexity than their counterparts. The main disadvantages can be summarized as:

- higher number of components
- higher weight
- more sophisticated vehicle electronic control strategies
- higher costs.

The hybrid powertrain structure and power size must be carefully selected to minimize the above mentioned disadvantages. Hybrid propulsion systems can be arranged, in a variety of configurations, in two basic categories: series and parallel (Fig 1).

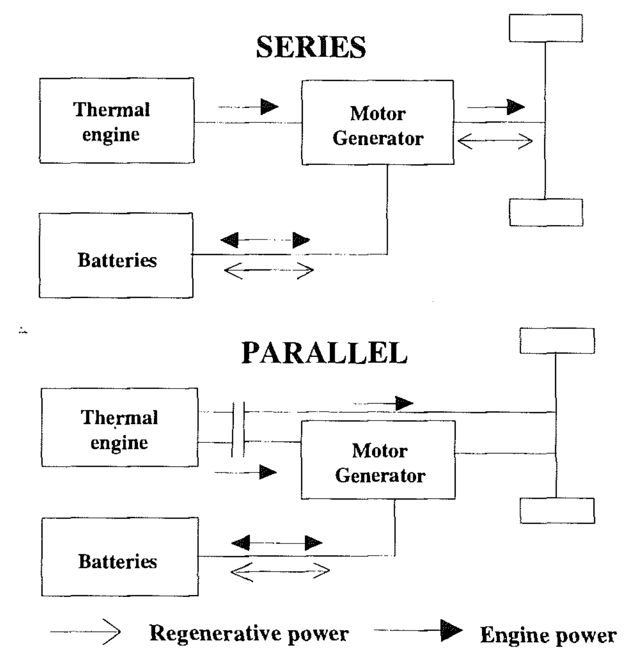


Figure 1

In the series arrangement, all energy from thermal engine is converted into electricity. The parallel arrangement has in addition a direct mechanical connection to the transmission driveline which could include a conventional gearbox. The topology and the details of a hybrid propulsion system will depend heavily on the mission that the vehicle is intended to fulfill and on the constrains of today's technology availability for mass

The global objectives of Fiat MULTIPLA hybrid vehicle and its powertrain subsystems characteristics are discussed in the following paragraphs.

MAIN VEHICLE OBJECTIVES

The goal of the present research activity is to design a hybrid vehicle, suitable for mass production, derived from the "MULTIPLA" equipped with a 1.6 litres gasoline engine, with similar characteristics as far as it concerns comfort, habitability and safety.

The daily vehicle mission could be summarized as 105 km per day with 1/3 on urban driving in hybrid mode, 1/3 in pure electric and 1/3 in hybrid mode on extraurban driving.

The emission levels must be equivalent to ZEV in pure electric and according to the European limits for year 2005 (EEC phase IV) in hybrid or thermal mode. Tab 1 shows the main vehicle performance requirements.

Performance requirements		Hybrid	Thermal	Electric
Top speed (km/h)		≥ 150		≥ 100
Continuous speed (km/h)		≥ 130	≥ 130	≥ 80
Acceleration (s)	0 – 100 km/h	<18	>30	-
	0 – 80 km/h	<12	<20	<40
	0 – 50 km/h	<6	<9	<13
Acceleration 3rd gear (s)	40 – 80 km/h	<10	-	-
Fuel consumption (ECE+EUDC) (l/100km)		-	<10	-
Emission		ECE IV	ECE III	ZEV

Table 1

In this paper the impact of these requirements on the powertrain will be examined.

POSSIBLE HYBRID CONFIGURATION

Throughout a preliminary investigation with mathematical simulation models, the deployment of overall objectives has been performed into subsystems specification as a function of possible powertrain configurations. For each of the possible solutions a weighted analysis of positive and negative aspects has been carried out.

follows:

Dual mode - The addition of an independent electric power train on the thermal vehicle leads to the simplest hybrid configuration. The two power trains operate in alternative, to meet the requirements of the circulation in typical urban areas (electric traction) or those of the extraurban missions (thermal engine).

Typical mission: extraurban driving, with limited operation in ZEV urban area.

Advantages:

- simplicity
- no integration of the two powertrain possibility to have a two axles drive system in case of critical mobility

Disadvantages:

- critical layout due to the two traction axles, with considerable modification on structure and mechanics;
- not optimized system in terms of energy consumption and emissions

Series Hybrid - The thermal engine coupled to an electric generator is used as a generating unit and motion is assured by an electric power train.

Typical mission: driving in large ZEV urban area

Advantages:

- small size thermal engine and its utilization within the most favorable working conditions in terms of efficiency and emissions;
- gearbox is not mandatory
- equal vehicle performance in electric and hybrid modes.

Disadvantages:

- number of installed components which have impact on the vehicle in terms of weight, volume and cost
- low efficiency over constant speed as a consequence of the energy conversions
- performance and operating range limited by battery

high installed electric power

on the same shaft their respective torque to achieve the desired performance.

Typical mission: ZEV urban driving and full-performance extraurban driving

Advantages:

- low installed electric power, related to the urban mission
- thermal engine can be downsized without penalizing vehicle performance leading to a fuel economy benefit.
- operating range in hybrid mode depending on vehicle fuel tank only
- addition of electric power to the thermal for peak performance
- flexibility in changing the vehicle mission.

Disadvantages:

- mechanical complexity
- gearbox and specific coupling interface needed
- system control complexity due to the management necessity of the two propulsion systems.

The vehicle mission and performance, the uncertainties of the evolution of the market, and cost constrain, requiring a strong attention to the "carry over" opportunities among the various production vehicles, have led to the choice of the parallel configuration (fig.2).

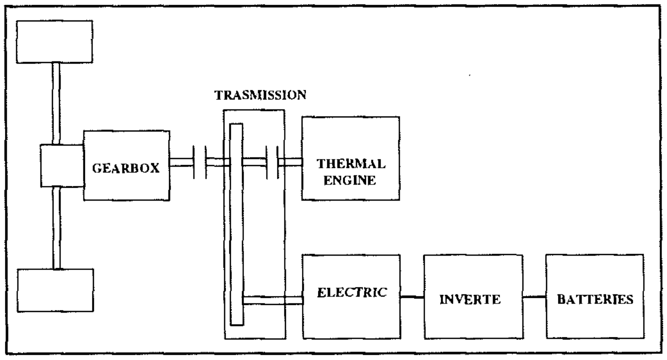


Figure 2

POWERTRAIN DESCRIPTION

Fig. 3 shows the powertrain where the thermal engine, the electric motor, the interface and gearbox are visible.

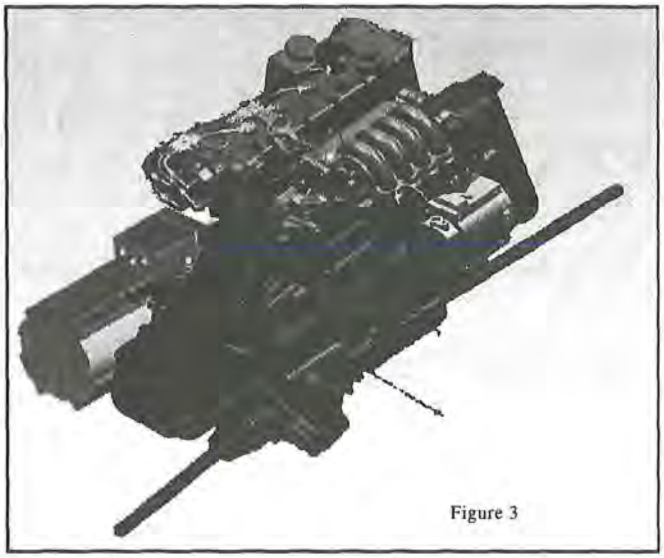


Figure 3

Thermal engine

The thermal engine chosen for this application is the new FIRE 1242 16 valves, just in production on the Lancia Y and on the Fiat PUNTO. An engine section is visible in fig. 4 and fig. 5 shows the engine torque and power characteristics.

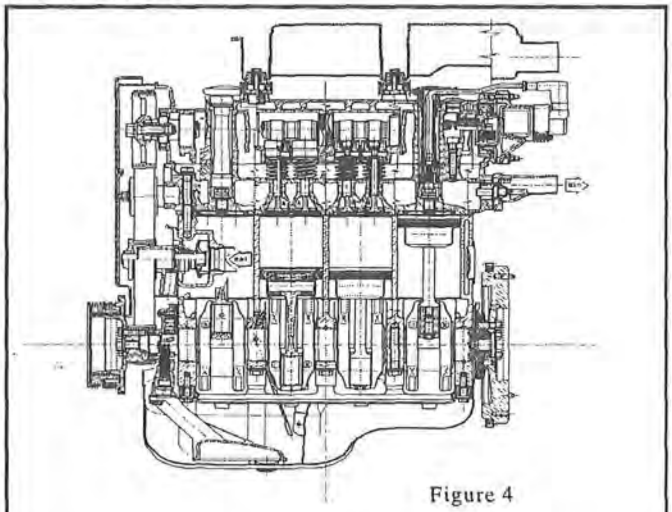
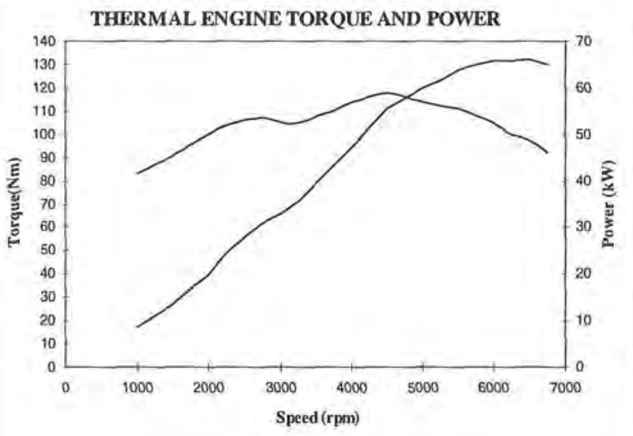


Figure 4



For the hybrid application some modifications of the series production thermal engine are required, mainly in the electronic control package which features a drive-by-wire system. Engine ECU re-calibration is of course necessary to optimize fuel economy, emission and driveability for the hybrid application. Table 2 reports the main engine characteristics.

ENGINE CHARACTERISTICS Table 2	
Weight	106 kg
Height	670 mm
Length	600 mm
Width	550mm
Displacement	1242cm^3
N. valve	16
Compression ratio	10.2
Injection system	MPI
Max torque	115Nm@4750rpm
Max power	65.5kW@6250rpm

The choice of a gasoline engine versus a diesel engine has been done mainly because the handicap of the diesel engine is the relatively high NOx emission, which with today's technology cannot be reduced to the same extent as a gasoline engine equipped with a three-way catalyst.

Electric motor and inverter

The electric drive system is based on an induction motor with vector control inverter.

Table 3 and table 4 reports the main motor and inverters characteristics.

ELECTRIC MOTOR CHARACTERISTICS Table 3	
Base speed	2500 rpm
Maximum speed at rated power	9000 rpm
Cut-off-speed (max. power peak)	6500 rpm
Over speed @ zero torque	10000 rpm
Rated torque	65 Nm
Max torque (5')	123 Nm
Rated power	15 kW
Max power (5')	30 kW
Peak power @ max peed	22 kW
Weight	41.5 kg
Diameter	200 mm

INVERTER CHARACTERISTICS Table 4	
Control algorithm	Torque - vector
Power switches	IBGT
Switching frequency	6 kHz
Power section input voltage	
Rated	160 - 260 V
Allowed	140 - 280 V
Control section input voltage	6 – 16 V
Max input current	280 A
Weight	17 kg
L x W x H	440x204x176 mm

Fig 6 shows the motor torque and power characteristics.

ELECTRIC MOTOR TORQUE AND

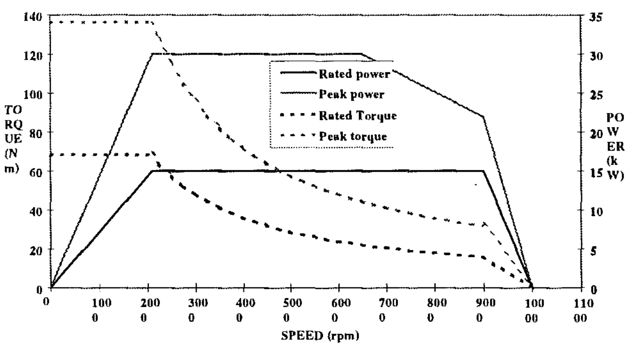


Figure 6

The motor features a low weight, reduced dimensions, and high utilization range with good efficiency (fig. 7).

Electric motor and inverter mesured efficiency
1st quadrant @ voltage 240 [V]

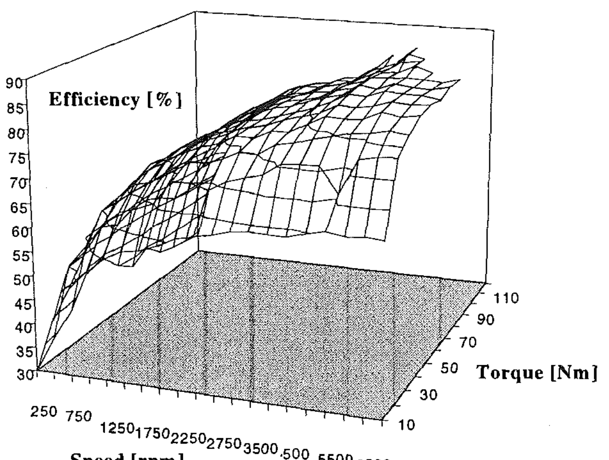


Figure 7

The motor, the inverter and the battery management have been designed for the application to the Fiat 600 electric vehicle, under development at Fiat Auto and Elasis.

Transmission

To minimize modifications and to make the solution compatible with the industrial needs, the integration of the two engines has been implemented through a parallel axle transmission (fig. 8).

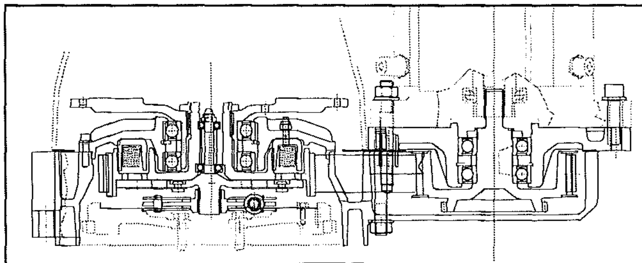


Figure 8

The mechanical coupling between the two axles is performed throughout a toothed belt. An electromagnetic clutch has been designed and manufactured to the connection and disconnection of the thermal engine. This allows for an automatic switching from electric to hybrid mode during vehicle operation, based on the drive train control strategies. The transmission to the vehicle wheels is performed by a normal production manually shifted 5 speed gearbox.

The main results of a simulation activity on vehicle performance with the above described powertrain components is shown in table 5.

PERFORMANCE		HYBRID	THERMAL	ELECTRIC	REFER. CONV. VEHICLE
Top speed (km/h)		176		116	173
Continuous speed (km/h)		166	148	86	
Acceleration (s)	0 – 100 km/h	15.5	26.8		12.4
	0 – 80 km/h	10.5	17.9	28.0	8.3
	0 – 50 km/h	4.9	8.7	10.3	4.1
Acceleration in 3rd (s)	40 – 80 km/h	8.3	17.6	21.0	7.5
Acceleration in 4th (s)	60 – 100 km/h	12.0	28.1		10.8
Acceleration in 5th (s)	80 – 120 km/h	18.3			15.9

Table 5

VEHICLE OPERATING MODES

The driver can select between the following four operating modes:

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