S Y M P O S I U M P R O C E E D I N G

Volume 2, Sessions 3A-6D
Poster Sessions

THE 12TH INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM (EVS-12)
and Electric Vehicle Exposition

Presented by **Electric Vehicle Association of the Americas (EVAA)**

Sponsored by
Edison Electric Institute
Electric Power Research Institute
Ford Motor Company
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Page 1 of 40

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DECEMBER 5–7, 1994
DISNEYLAND HOTEL AND CONVENTION CENTER
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EVAA

The Electric Vehicle Association of the Americas (EVAA) is a not-for-profit association comprised of utilities, automobile and component manufacturers, universities, governmental agencies, and others mobilized to facilitate the commercialization of on-road electric vehicles. Proceedings from EVS-12 may be obtained by writing EVAA at 601 California Street, Suite 502, San Francisco, California 94108.

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INTERNATIONAL ELECTRIC VEHICLE SYMPOSIA

EVS-1	November	1969	Phoenix, Arizona, U.S.A.
EVS-2	November	1971	Atlantic City, New Jersey, U.S.A.
EVS-3	February	1974	Washington, D.C., U.S.A.
EVS-4	September	1976	Dusseldorf, Germany
EVS-5	October	1978	Philadelphia, Pennsylvania, U.S.A.
EVS-6	October	1981	Baltimore, Maryland, U.S.A.
EVS-7	June	1984	Versailles, France
EVS-8	October	1986	Washington, D.C., U.S.A.
EVS-9	November	1988	Toronto, Ontario, Canada
EVS-10	December	1990	Hong Kong, China
EVS-11	September	1992	Florence, Italy
EVS-12	December	1994	Anaheim, California, U.S.A.

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TECHNICAL BREAKOUT SESSIONS

Session 3A: Drives

Session 3B: Battery Modeling

Session 3C: Infrastructure

**Paper not available at time of printing.*

Session 5C: EV Policies

Session 5D: National Electric Vehicle Infrastructure Working Council

Session 6A: Components

**Paper not available at time of printing.*

**Paper not available at time of printing.*

Session 6D: National Electric Vehicle Infrastructure Working Council

POSTER/DIALOGUE SESSIONS

Electric Vehicles and Hybrid Electric Vehicles (Safety; Components; Simulation)

**Paper not available at time of printing.*

**Paper not available at time of printing.*

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Hybrid Drives

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Session 5B:
Batteries

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Japan Electric Vehicle Association (JEVA)

Russell Moy
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Session 5C:
EV Policies

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Session 6C:
Demonstrations

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CALSTART

Session 6D:
National Electric Vehicle Infrastructure Working Council

Roland Risser
Pacific Gas and Electric Company

Poster/Dialogue Session:
Electric Vehicles and Hybrid Electric Vehicles

Alan Gilbert
Unique Mobility, Inc.

Poster/Dialogue Session:
Electric Vehicle and Hybrid Electric Vehicle Batteries

Ray Hobbs
Arizona Public Service Company

Poster/Dialogue Session:
Drive Systems and Motors

Chris Borroni-Bird
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Poster/Dialogue Session:
EV Infrastructure

Ronn E. Jamieson
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Poster/Dialogue Session:
Introduction, Demonstration and Test

Larry Brandenburg
Ford Motor Company

Poster/Dialogue Session:

Electric Vehicles and Hybrid Electric Vehicles

(Safety; Components; Simulation)

FIAT CONCEPTUAL APPROACH TO HYBRID CARS DESIGN

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Abstract

In this paper the different motivations behind the development of hybrid cars are examined and various hybrid configurations are illustrated which can satisfy a wide range of different and contrasting user needs.
Specific attention is then given to the definition of guidelines for the development
of a hybrid car where parallel configuration of the propulsion system allows the fulfillment of two types of mission:

- short trips in urban areas with zero emissions by only using the electric motor driveline;
- long highway trips with performance close to that of conventional cars but lower emissions.

The corresponding design criteria for a Fiat medium size hybrid car are described together with the propulsion system, consisting of an A.C. electric motor and an ICE, that has been implemented and bench tested. A prototype car has also been equipped with this hybrid system and the driveability demonstrated.
The management of the two propulsion units: electric motor and ICE is performed via an ECU using suitable control logics to optimize, in terms of consumptions, emissions and battery energy management, the performance of the global system.

Introduction

In the last years the legislation scenario and the attention to the environmental issues have changed, also in relation with the inconvenience produced by the traffic density in the most congested urban centers; as a consequence the research and development effort of the automotive and component manufacturers has changed, in order to better cope with the problems which did not allow up to now an industrial development of the environmental friendly electrically

propelled vehicles.
The range and performance limits which are tied to the characteristics of the batteries presently available or under development (power, energy, weight, volume) remain the principal obstacle against the electric traction diffusion, even within the assumption of the european scenario which forecasts the establishment of areas with circulation reserved to ZEV vehicles.
A recent study of the MIP Consortium in Milan has put in evidence that only 10% of the vehicles in circulation in the Milan area could be substituted by electric vehicles, provided that they can assure a real range of 85 Km. On the contrary, the hybrid vehicles, featuring a range in pure electric of some 40 Km, would allow a substitution of approximately 90% of the vehicle park.
This study, whose results can be extended to other italian and european cities, puts in evidence the enormous potential of hybrid vehicle.
The introduction of such a vehicle into the market, could have indeed an important impact on the enviromental quality improvement of the more congested urban areas and, in general, on the global pollution.

Alternative hybrid vehicle configurations

The hybrid vehicle features a powertrain which integrates a thermal engine with an electric motor.
Toward the hybrid vehicle approach, various possible configurations have been examined. [1]
The addition of an independent electric powertrain on the thermal vehicle originates the simplest mixed configuration, called "dual mode".
The two powertrains operate in alternative, to meet the requirements of the circulation in typical urban areas (electric traction) or those of the extraurban missions (thermal engine).
This configuration allows the following advantages:

- it does not require the integration of two powertrains; as a matter of fact, the simplest configuration is related to a conventional front drive ICE to which an electric powertrain is added on the rear axle.
- it offers the possibility to make available a drive system on the two axles in the cases of critical mobility.

On the other hand, some constraints exist:

- critical layout due to the encumbrances on the two traction axles, with considerable modifications on structure and mechanics;
- vehicle performance in the thermal mode penalized by the higher weight due to electric motor, related electronics and batteries;
- system not optimized in terms of consumption and emissions.

Another possible configuration is the series hybrid, which is constituted by a generating unit (thermal engine/electric generator) and by the electric powertrain.
For this configuration, the following advantages are envisageable:

- utilization of the thermal engine within the most favourable working conditions in terms of efficiency. This offers the possibility, for a mission featuring variable speed and low power, of limiting the emissions of the traditional pollutants, to the minimum allowed by the technology;
- equal vehicle performance in the electric and hybrid modes.

On the other hand, the most important disadvantages of this configuration are:

- the number of installed components (two electrical machines besides the thermal engine), which have an impact on the vehicle in terms of weight, volume and cost;
- low efficiency over constant speed runs, as a consequence of the energy conversions (thermal-electrical-mechanical).

A further possible configuration is the parallel hybrid.
This solution, albeit a higher mechanical and system complexity, utilizes the combination of the two engines (thermal and electric), adding on the same shaft the respective torque and power to achieve the desired performance.
In this case the advantages of the system can be summarized as follows:

- low installed electric power, related to the urban mission, with consequent weight and volume reduction;
- possibility of a direct conversion of the thermal energy into mechanical, with higher global efficiency of the system;
- addition of the electric power to that of the thermal engine, with power peaks covered by the electric motor.

However, it is necessary to overcome the critical aspects deriving from the integration of the two systems, that are:

- mechanical complexity;
- complexity of the system for control and simultaneous management of the two propulsion systems.

As far as the cost aspect is concerned, taking as a reference an electric vehicle of the same size, the hybrid vehicle would feature as follows:

- the electric motor is of slightly smaller power;
- the battery can be of lower capacity (roughly one half);
- a thermal engine of relatively low power is added which is taken from the conventional mass production;
- a mechanical transmission is substituted to that of the electric vehicle; a specific mechanical interface is added.

Therefore, in this preliminary development phase, a not unreasonable goal would be a substantial equivalence of cost between the parallel hybrid and a pur electric vehicle of the same size.

Research and development activity in FIAT

The optimum choice of the hybrid vehicle configuration is strictly connected with the mission. FIAT R&D activities in the field of electric traction are lined up to the development trend in Europe, where the reference mission can be summarized as follows:

- city centers with mobility restricted to ZEV vehicles
- extraurban and motorway runs with performances comparable to those of conventional vehicles.

The uncertainties of the evolution of the market and of the introduction procedures of the regulations did not prevent activities on large fields of investigation, both to assess the different technology options and to identify the best synergy of thermal/electric/hybrid vehicle.
The cost constraint requires a strong attention to the carry over among the various vehicles and in particular to the conventional normal production vehicle.
Research activities have been started on a hybrid vehicle with parallel configuration, derived from a conventional medium size car; pursuing the best compromise among technical complexity, cost and performance, keeping the same characteristics of roominess, comfort, active and passive safety; in particular, design solutions have been followed which limit the required modifications on the basic vehicle and optimize the number of components drawn from the conventional vehicles already in production, keeping the final price of the product within acceptable values.
In order to verify the functionality of the whole system and the potential of the technical choices, a demonstrator prototype of the hybrid vehicle has been designed, manufactured and tested both at the test bench and on the road.
The global objectives of the vehicle, the specifications of the subsystems and the preliminary experimental results are discussed in the following paragraphs.

Overall objectives and systems specifications

The performances of the hybrid vehicle compared with those of the basic conventional vehicle are shown in Tab. 1, with reference to the operating modes electric and hybrid; the use of the pure "thermal" traction is considered only for the cases of some anomalous behaviour of the system.
Throughout a preliminary investigation with mathematical simulation models, the deployment of the overall objectives has been performed into subsystem specifications.
Tab. 2 exhibits the characteristics of the main group of the hybrid system. In this first phase of the project, the maintenance free Pb/Gel battery has been considered for the energy storage system.
This choice does not hinder the further use of new batteries for the optimization of the system in terms of weight and encumbrances.

Vehicle Packaging

The hybrid vehicle under study is derived from the conventional model of normal production FIAT TEMPRA, which features a weight of some 1100 Kg and the following external dimensions:

- Length= 4354 mm; width= 1695 mm; Height= 1445 mm

The conversion requires a careful analysis of the main design constraints, which bring to a deep review of the layout of all subsystems, with a considerable weight increase related to the energy strorage system and to the double drive system (Δ weight ~450Kg).
The established layout is shown in Fig. 1.
In order to obtain dynamic characteristics equivalent to those of a conventional vehicle, it has been necessary to redefine the main parameters of the suspensions (stiffness, damping) according to the new operating conditions.
In order to obtain the same working conditions and driving comfort within the different modes, electric and hybrid, power steering and power braking are supplied by electrical pumps.
The weight increase of approximately 40% over the basic vehicle has requested considerable modifications on the structure in order to make the hybrid vehicle consistent with the safety standards and with the strength and the stiffness of conventional vehicles.
Preliminary analyses performed by means of computer simulations have produced indications on the guidelines to follow in the definition of the structural modifications.
In order to make the interventions compatible with the industrial constraints, it has been decided to modify the structure mainly in the lower part, as shown in the scheme of Fig. 2. With reference to consumption and emissions, the developed solution allows to counterbalance the negative effects due to the weight increase, since it allows to:

- install a thermal engine of reduced power insofar the maximum performances are given by the sum of the power of the thermal engine and of the electric motor, with benefits in terms of overall efficiency at the same total output power;
- recover energy during braking phases, thus reducing the negative impact due to weight increase;
- use the electric motor and the thermal engine in the highest efficiency conditions, through the optimization of the control strategy of the system;
- reduce the emissions both in transient and starting conditions, through an appropriate control strategy.

Hybrid powertrain

In fig. 3 the main components of the hybrid powertrain are shown. Preliminary bench tests have been performed on all main components, in order to verify their characteristics in terms of performance, efficiency and encumbrances (Fig.4).

- Thermal engine
  - The thermal engine defined for this application (1242 c.c.) is taken from the series production and features an injection system MPI, which allows better potential in terms of emission control.
  The software of the electronic unit (WEBER IAW) has been modified to implement new control strategies in the transients and to achieve the stoichiometric control over the whole working range.
  Further interventions have been necessary to equip the powertrain with the DRIVE-BY-WIRE system.
- Electric motor
  - As a starting point for the development of this project, a synchronous variable reluctance motor with high torque and efficiency has been adopted [2].
  The motor, which has been designed for the application to an electric vehicle, features a high utilization range, low weight and reduced dimensions, which have been made possible by integrating the liquid cooling system both for the motor and for the inverter.
- Transmission
  - In order to reduce the modifications and, therefore, to make the solution compatible with the industrial needs, the integration of the two engines has been implemented through a parallel axles transmission scheme (Fig. 5).
  The mechanical coupling between the two axles is performed through a toothed belt of kevlar fiber reinforced polymeric material.
  An electromagnetic clutch has been designed and manufactured for the connection and disconnection of the thermal engine, for the automatic switching from the electric to hybrid mode also during vehicle run and for allowing higher flexibility within the definition and optimization of the control strategies.
  The power transmission to the wheels is performed by a manually shifted 5 speed gearbox of normal production.
- Control system
  - The hybrid system is managed by an electronic control unit (ECU), which implements the working strategies of the vehicle and activates the two drivetrains through respectively the inverter for the electric motor and the control unit for the engine.

  The electronic control unit will also have the following functions:
  - management of the dashboard warning lights which, besides the conventional warnings, also signal system trouble (high engine temperature, motor/inverter breakdown);
  - monitoring of the battery discharge current which gives the driver the possibility to have informations on S.O.C. and on the residual operating range.

Management strategies of the hybrid powertrain

With reference to the configuration scheme shown in Fig. 5, the electronic control unit (ECU) manages the powertrain on the basis of the inputs of the accelerator and brake pedals, discriminating between the two modes, electric and hybrid, which are selected by the driver by means of a switch, also while the vehicle is running.

In the electric mode the accelerator pedal position defines the requested torque to the drivetrain.
By completely releasing the pedal a "regenerative braking" occurs; the braking effect, and the corresponding energy recovery is increased by pushing the brake pedal.
This constitutes a real opportunity to increase the range of the vehicle in ZEV areas, where frequent acceleration and deceleration phases occur.
For some reference cycles, Fig. 6 and 7 show the percentage of the kinetic energy which is possible to recover.
In the hybrid mode, both electric motor and thermal engine are "active"; the thermal engine is controlled through the DRIVE-BY-WIRE system.
The driver, through the accelerator pedal position, sets the total traction torque; this is splitted between the two drivelines in such a way to meet the following objectives:

- To assure a good driveability of the vehicle:
  - the torque splitting between the two drivelines occurs automatically. Therefore the driveability is totally similar to that of a conventional vehicle with manual gearbox.
- To optimize the consumptions:
  - by means of the regenerative braking and of control strategies optimized in such a way that the braking torque during the deceleration phases is supplied by the electric motor (the thermal engine is disconnected).
    Depending on the state of charge of the batteries and on the autonomy range set by the driver (in hybrid mode it is possible to recharge the batteries) the control system allows also to introduce only the electric traction in the phases in which the thermal engine would be requested to work in low efficiency conditions.
- To reduce the emissons:
  - the vehicle has been equipped with a heated catalyst, by which the warm-up of the main catalyst is performed while the thermal engine works at minimum r.p.m.;
    in any case, the vehicle operation in this phase is assured by the electric driveline.
    A further contribution to the emission reduction is achieved through the "steady state" management of the thermal engine in transient phases, while the torque demand is assured by the electric motor support (Fig. 8).

The sistem is designed in such a way to allow the battery recharge from the mains, either overnight, or through external interim recharge from infrastructure facilities.
This possibility allows to achieve an improved overall energetical figure, also according to the concept to use alternative primary energy sources and to use the overnight electricity.

Prototype

In order to validate on vehicle the suitability of the developed solutions in terms of driveability, performance, fuel consumption and emissions, a prototype has

been manufactured and tested (Fig. 9). The experimental results related to the performances are summarized in Tab. 3 and show a substantial equivalence between the reference conventional vehicle and the hybrid prototype, putting in evidence for the hybrid prototype a considerable reduction of acceleration times from 40 Km/h. This condition is especially connected with the choice of a parallel hybrid configuration, which allows to add to the thermal engine power the whole electric motor power in every working condition.
Fig. 10 shows the preliminary consumption results over some driving cycles obtained with a simplified control strategy which does not include, in particular, the regenerative braking.
The results show that, despite the weight increase and with simplified control, the hybrid vehicle features a fuel consumption comparable with that of a conventional vehicle. This means that, with an optimized control strategy, including regenerative braking, the fuel consumption can be expected to be lower than that of a conventional vehicle.
According to test results, the range over the urban cycle in pure electric mode is 42 Km (Fig. 11). Furthermore, preliminary tests have demonstrated the functionality of the system and the achievement of the driving comfort targets in all the different operating modes, without critical aspects in the phases of simultaneous management of the two drivelines.

Conclusions

A hybrid vehicle prototype, derived from a normal production car, has been designed, manufactured and tested.
The achieved preliminary results show the real possibility for the parallel hybrid configuration to meet the most demanding mobility requirements in the framework of the established mission, with fuel consumption and performance equivalent to those of the conventional vehicles and with global emissions reduced. In particular, fuel consumption has been demonstrated by preliminary testing results, to reach levels comparable with those of the reference vehicle, despite of higher weight, with a further reduction potential through optimized control strategy including regenerative braking.
Furthermore the developed solution has put in evidence the possibility of using, for the powertrain, common components of series produced cars (carry over), being compatible with medium size vehicles.
Moreover, an extended experimentation, actually being carried out on the prototype, will supply further indications and data for future development on components and on optimum control strategies.

References

[1] "European hybrid technology development approaching efficient zero emission mobility (HY-ZEM)" - S. Friedmann et al. - Proceedings of the 4th ATA International Cenference "New design Frontiers for More Efficient, Reliable and Ecological Vehicles" - Florence, Italy, march 1994.

[2] "Traction motors for electrically propelled vehicles" - G. Brusaglino - Revue Géneral de l'Electricité, ISSN 0035 - 3116, n° 10, November 1993, p. 65-68.

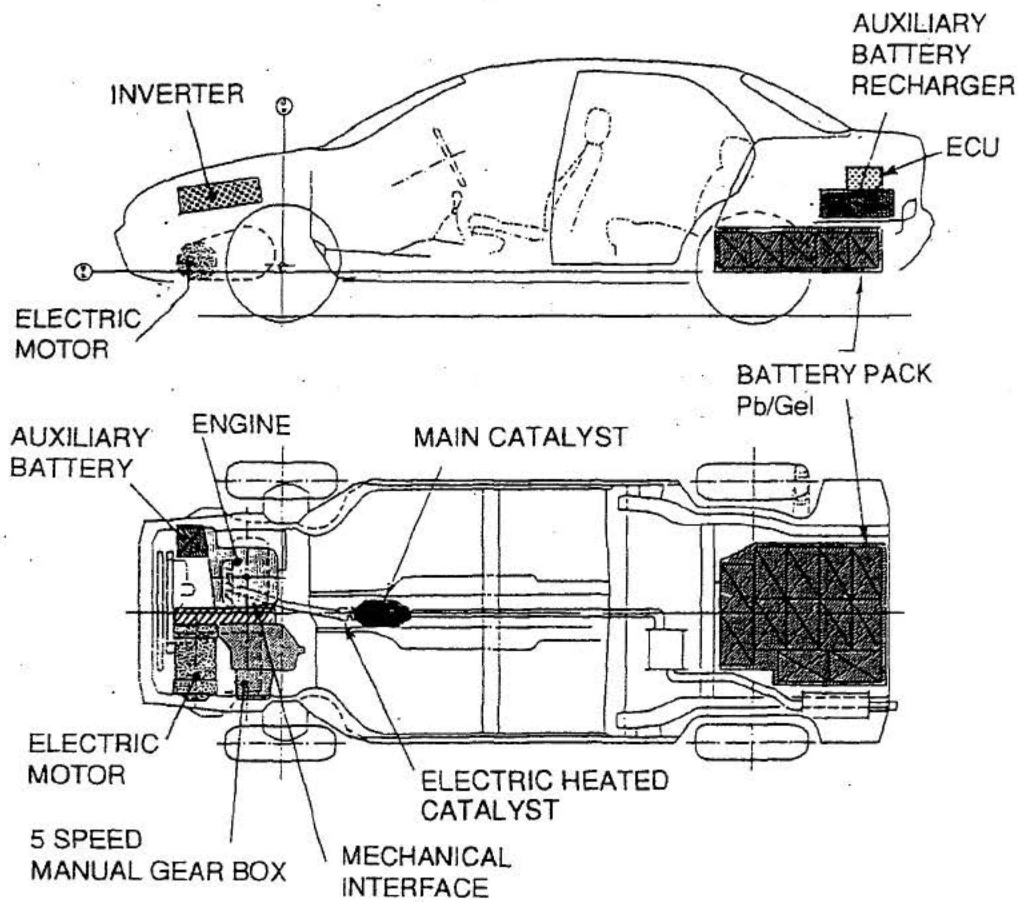

FIGURE 1
VEHICLE PACKAGING

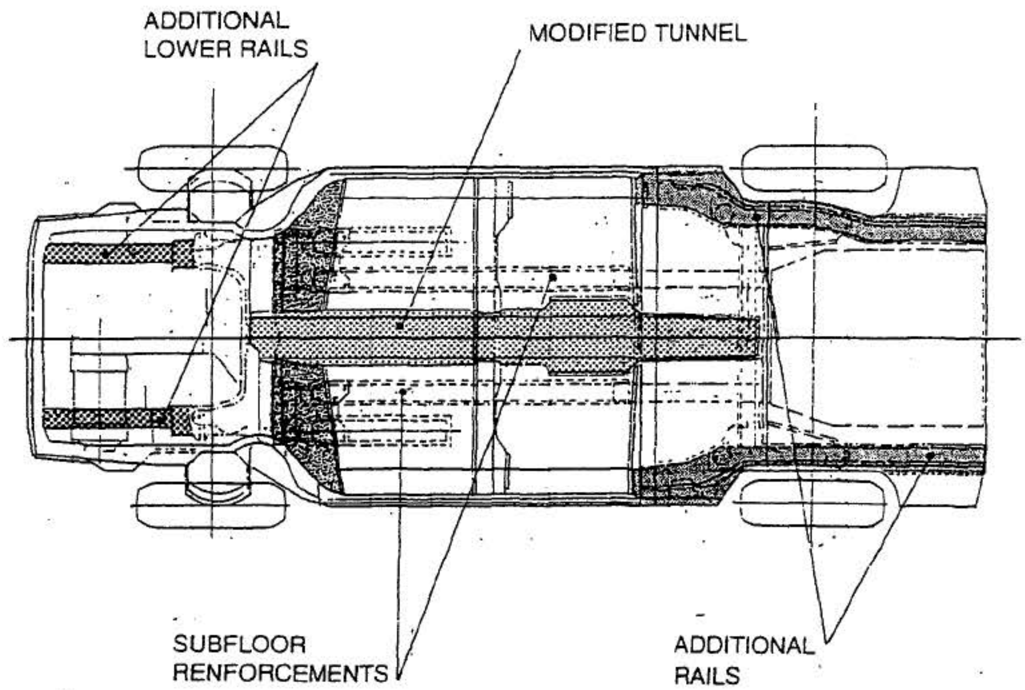

FIGURE 2
STRUCTURAL LAYOUT

FIGURE 3
POWERTRAIN UNIT

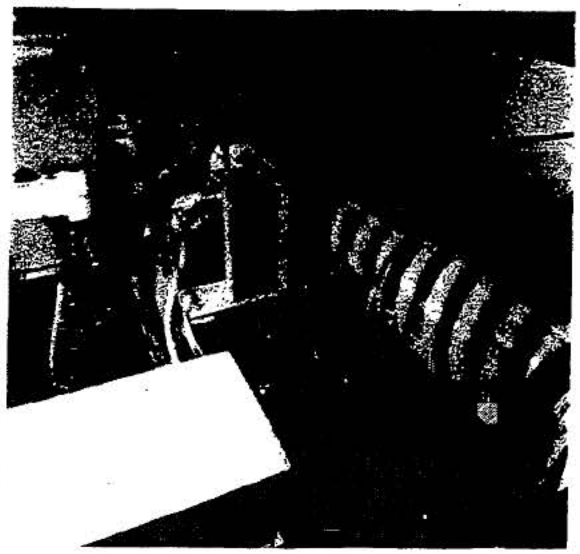

FIGURE 4
POWERTRAIN BENCH TEST

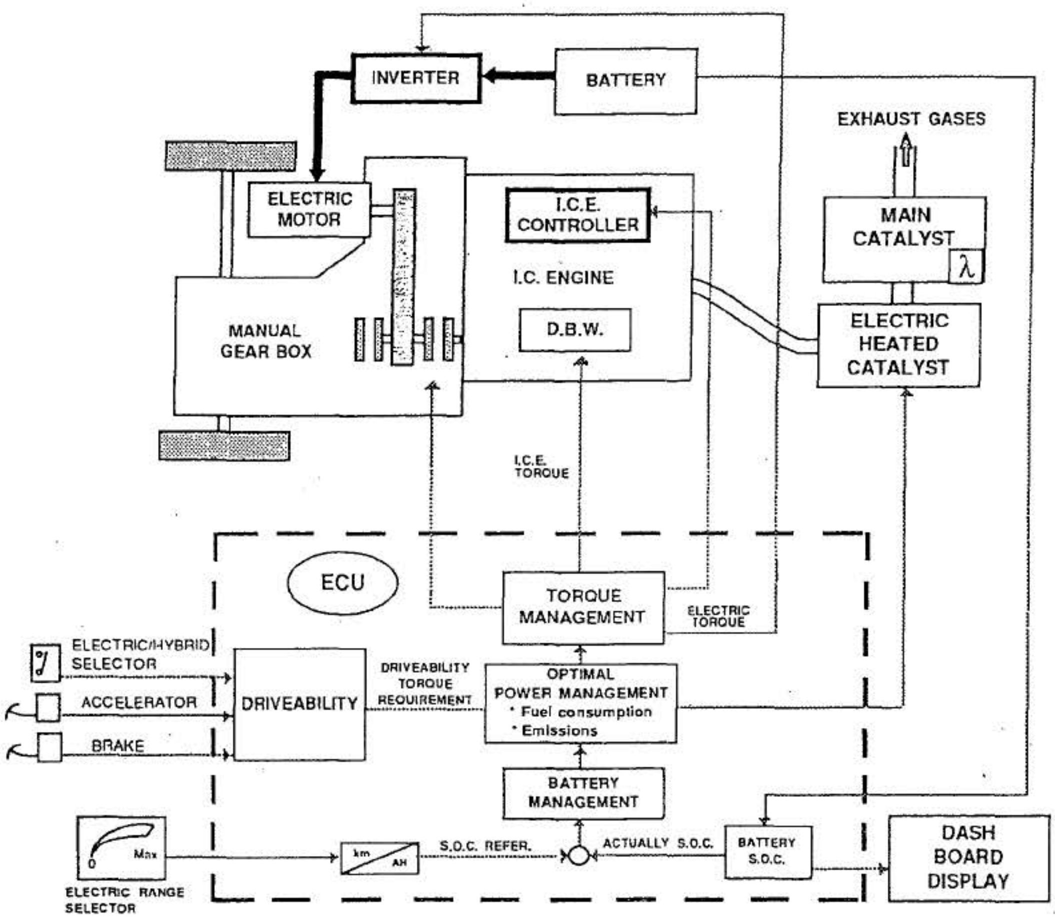

FIGURE 5
HYBRID CONTROL SYSTEM LAYOUT

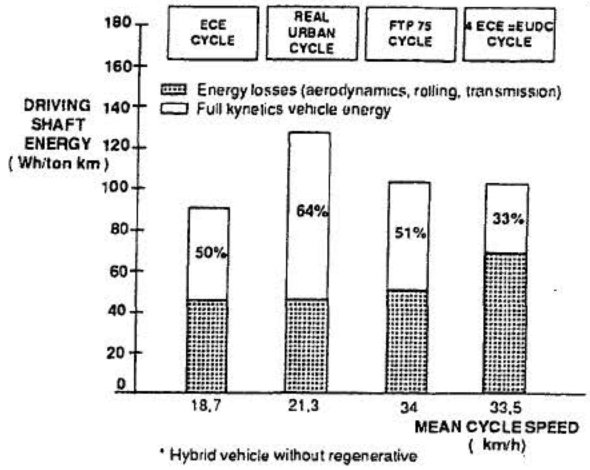

FIGURE 6
VEHICLE ENERGY DISTRIBUTION

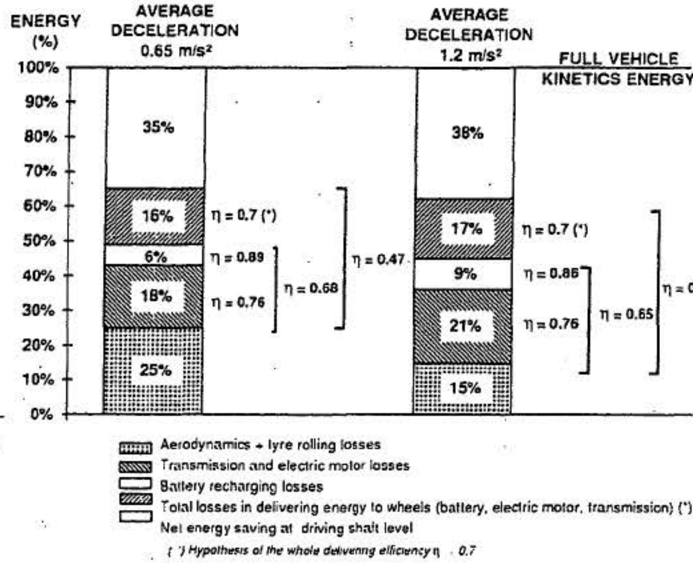

FIGURE 7
EXPERIMENTAL TESTS ON REGENERATIVE BRAKING EFFICIENCY

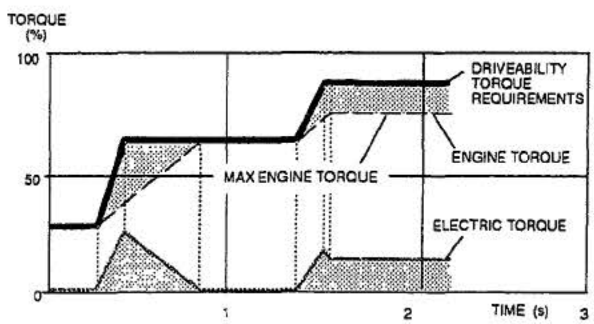

FIGURE 8
DRIVING TORQUE MANAGEMENT

FIGURE 9
FIAT TEMPRA HYBRID PROTOTYPE

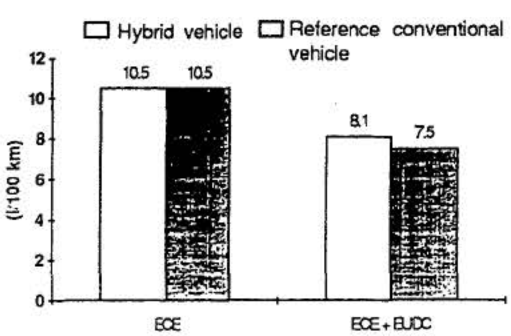

FIGURE 10
FUEL CONSUMPTIONS

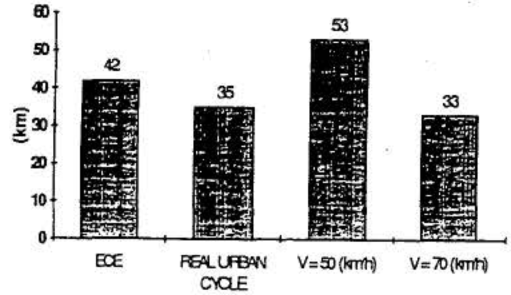

FIGURE 11
ELECTRIC RANGE

	ELECTRIC MODE	HYBRID MODE	REFERENCE CONVENTIONAL VEHICLE
TOP SPEED (km/h)	80	155 (130 continuous)	160
ACCELERATION (0-50 km/h) (s)	12	5	4.5
MAX GRADEABILITY (%)	25	25	25
RANGE (ECE CYCLE) (km)	35	250	-
EMISSION	ZEV	Less than reference conventional vehicle	-
CONSUMPTION	-	As the reference conventional vehicle	-

TABLE 1
HYBRID VEHICLE REQUIREMENTS

ENGINE	* Max power 55 kW (6000 RPM) * Max torque 110 Nm (1500 RPM) * Electric heated catalyst
ELECTRIC MOTOR	* Peak power 21,5 kW (nominal Power 12 kW) * *Peak torque 130 Nm (Nominal Torque 75 Nm)* * Liquid cooling
TRANSMISSION	* Mechanical interface (engine/electric motor) with electromagnetic clutch and polymeric belt * Five speeds manual gear box
BATTERY PACK	* Lead-gel maintenance free * Voltage 216 V * Energy 10.8 kWh * Mass 360 kg

TABLE 2
POWERTRAIN CHARACTERISTICS

PERFORMANCES		ELECTRIC	HYBRID	REFERENCE CONVENTIONAL VEHICLE
TOP SPEED (km/h)		98	158	160
ACCELERATION	0÷50 km/h (s)	13	5.9	5.5
	0÷400 m (s)	-	21.6	20.5
ACCELERATION IN IV FROM 40 km/h	40÷80 km/h (s)	31.6	11.2	15
	40÷100 km/h (s)	-	19.6	22.2

TABLE 3
HYBRID PROTOTYPE PERFORMANCE

EVS-12

Volume 2

Sessions 3A-6D

Poster Sessions

SYMPOSIUM PROCEEDINGS

Electric Vehicle Association of the Americas (EVAA)
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San Francisco, California 94108

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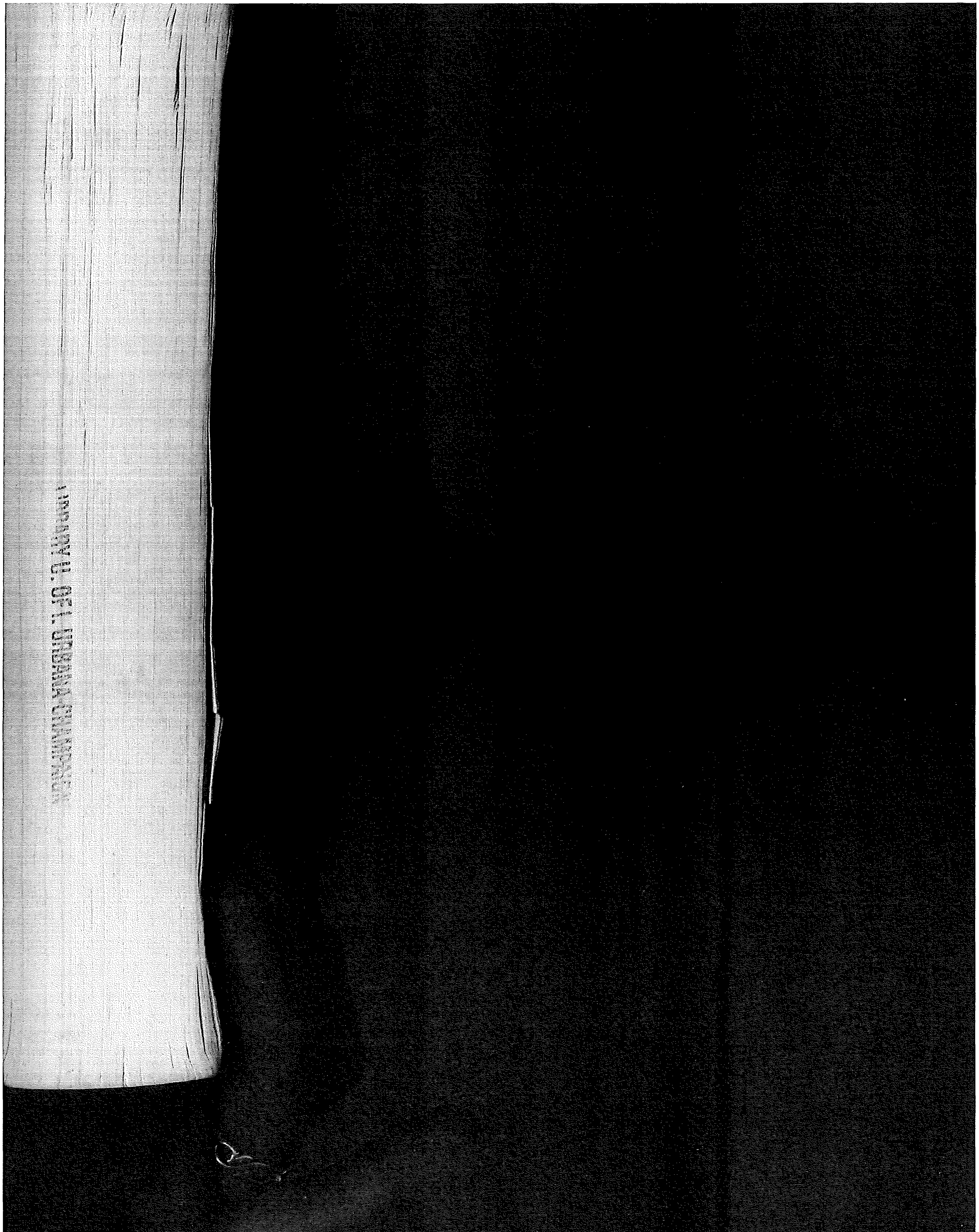

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