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DESIGN, DEVELOPMENT AND CONSTRUCTION OF A FUEL CELL VEHICLE- HERCULES PROJECT.

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Abstract:

"Hercules" Project, started in January 2006 and planned to finish at mid 2009, has been structured around a dual purpose: to demonstrate the technical and economic feasibility of hydrogen production from renewable solar energy; and validate the use of hydrogen in fuel cells in the automotive sector. To achieve these goals the cooperation of various companies and research groups is needed, specialists in each of the technology areas that are addressed in the project; so that, a Spanish consortium of private companies, a public research body, a researchers association and a public agency has been formed.

As part of this consortium, the overall "Hercules" Project has been divided into three sub-projects:

- “Las Columnas”, whose goal is the development and construction of the renewable hydrogen, from solar photovoltaic energy, production and refuelling plant.

- “El León”, to integrate new technologies in the automotive sector, improving energy efficiency and providing environmental benefits.

- "El Olimpo", which performs the overall project coordination, evaluation, technology transfer, diffusion and dissemination of results.

Keywords: solar hydrogen, fuel cell vehicle, automotive sector

1. Introduction:

The objective of the "Leon" subproject is to use new and efficient environmental friendly technologies in the automotive sector, to advance in the development of automobiles more respectful with environment and able to operate with alternative fuels to those of fossil origin with greater power efficiency than the conventional vehicles.

To achieve these objectives, a non-pollutant vehicle, which replaces the part of the conventional powertrain of a commercial vehicle with a new power system consisting of a fuel cell stack fed with pure hydrogen, and an electric motor, is being developed.

2. Fuel cell vehicle description:

The platform for the project will be a commercial, light-duty, 4x4 vehicle that uses compressed hydrogen as the fuel for a solid polymer fuel cell stack.

The vehicle's main characteristics shall be:

- Light-duty 4x4 vehicle (Santana 350).
- Hybrid configuration fuel cell/batteries.
- Vehicle autonomy higher than 100 km.
- High efficiency electric wheel drive system comprising of an electric motor control system and regenerative braking that recovers the energy lost during braking.

- Reasonable cost together with economies of scale for future mass-produced components.
- Use of new technologies that can help generate employment.
- Development of a vehicle that can ensure the safety of the occupants and their surroundings.
- Comply with all the existing safety standards and tests for this type of vehicle.

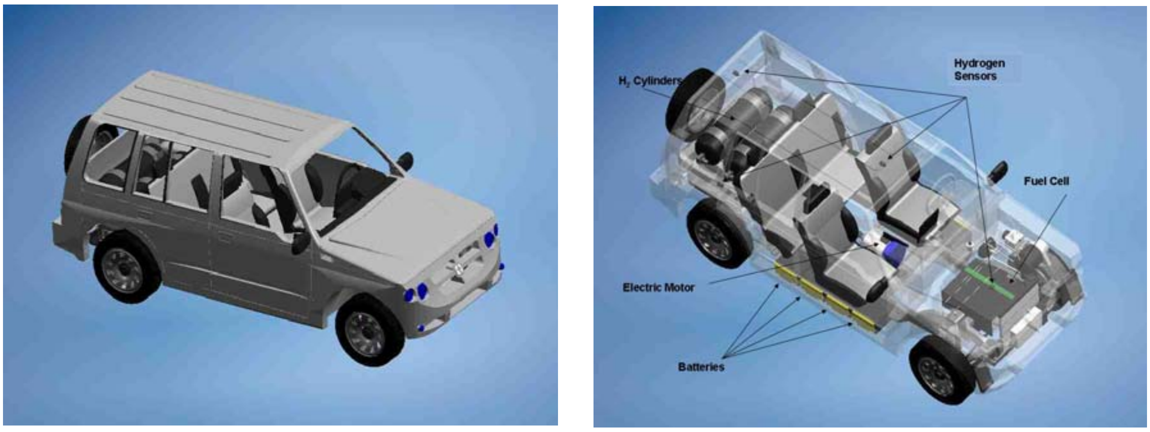

Figure 1 - Fuel cell vehicle diagram

The integration and adaptation of the entire vehicle, the selection and use of new materials, the fuel cell/battery system development, the power system control optimization from the energetic and weight point of view, the light compressed-hydrogen storage systems usage, all active and passive safety research for this type of vehicle, the interfaces between the vehicle and the fuelling system and the user information systems are such innovative processes that both, companies and investigation groups, face up to an interesting challenge.

3. Systems

3.1. Fuel cell power system

The fuel cell power system is the vehicle's main power source, transforming the compressed hydrogen chemical energy in electrical energy that feeds the traction motor.

Dimensions, configuration and operational parameters:

- Nominal power: 56 kW
- Voltage range (V): 150 - 247
- Maximum Current (A): 360
- Air flow (l min^{-1}): 580 - 2600
- Hydrogen Flow (l min^{-1}): 380 - 960 (it does not require humidification)
- Hydrogen purity (%): 99.995
- Volume (l): 56 l
- Weight (kg): 96
- Dimensions (mm): 480 x 220 x 578

Auxiliary Systems:

- Air compressor: Designed to reduce size and consumption
- Hydrogen recirculation pump: Designed to reduce size and consumption

3.2. Li-ION batteries power system

The vehicle has a hybrid configuration, in which part of the electrical energy provided to the motor comes from a set of high performance batteries. These batteries are loaded from the fuel cell and taking advantage of the energy recovered from the regenerative braking. Li-ION batteries have been selected because of weight, volume and operation conditions reasons.

The configuration selected is the following:

- Type: Li-ION
- Nº of modules: 8
- Connection of the modules: in series
- Total energy of the system (kWh): 9.5
- Nominal voltage of the system (V): 153.6
- Maximum standard discharge continuous current (A): 120
- Module length/width/height (mm): 268/148/269
- System volume (l): 90
- System weight (kg): 119

3.3. Thermal control system

The thermal control system is the responsible to dissipate the heat generated by the fuel cell and the electronic power conditioning systems, trying to change as less original components as possible. An effort to use the original radiator of the Santana's vehicle as air-water heat exchanger has been done.

The water pump to be used must be able to be fed with DC, have a reduced weight and be able to vehicular a water volume of about 100 kg min^{-1}. The circulation pump will be controlled by the fuel cell control system that must indicate the stop and start conditions and fix the water volume that it has to circulate.

3.4. Power conditioning system and electric traction design.

The power system is formed by a DC/AC power converter to which the fuel cell and the batteries are connected and that adapts the fuel cell operating conditions as well as those of the other energy storage elements. This converter is formed by three DC/DC converters joined to an inverter that is connected to the vehicle AC motor. The three DC/DC conversion stages are connected in parallel, and bidirectional converters are used for the batteries with the purpose of being able to use regenerative braking to load the batteries.

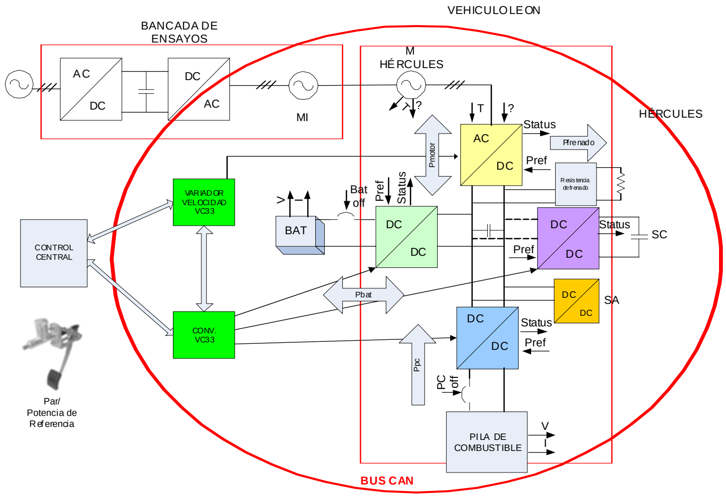

Figure 2- Power system general scheme

The control of the system must take into account the load demand and each element conditions every moment so that the control considers the load of the batteries. Two independent control systems have been contemplated, a variable speed device and another one for the fuel cell power system and the batteries, communicated by means of RS-485. The communication with the central control system has been adapted to the communication's protocol of the vehicle based on the CANBUS standard.

The traction system has also been designed to minimize the number of changes in the vehicle, and therefore the adaptation cost. In addition to the internal combustion motor, the gear box and the differential have been also eliminated. The selected electrical motor for the application has the following specifications:

- Type: synchronous of inner permanent magnets
- Terminal velocity to 150 km h^{-1} (r.p.m.): 5976
- Maximum power (kW): 64
- Maximum pair: 580.8 N·m from 0 to 2000 r.p.m
- Constant power from 2000 to 6000 r.p.m
- Dimensions and weight (maximum): diameter 300mm, length: 310 mm and 75 kg

Transmission system:

After considering several possibilities, finally rear transmission, direct coupling to power shaft has been selected because implies a simpler design of the electrical motor to be used.

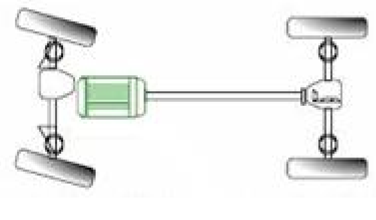

Figure 3- Rear transmission, direct coupling

3.5. Control and supervision systems design

The control system (ECU) is in charge to manage the power between the different vehicle systems. Each system has its own local control system, and the ECU determines the instructions that each local control system has to observe related to:

- Fuel cell power
- Batteries power (positive or negative)
- Electrical motor torque (positive or negative)
- Electrical braking power.

The ECU also manages the sequence and the way in which the different systems have to act during the vehicle's start and shutdown, as well as the alarms, and if needed, the sequence of a series of orders associated to these alarms. This alarm management system is complementary to the own security system that each vehicle's equipment has.

The communications have been implemented with CANBUS protocol.

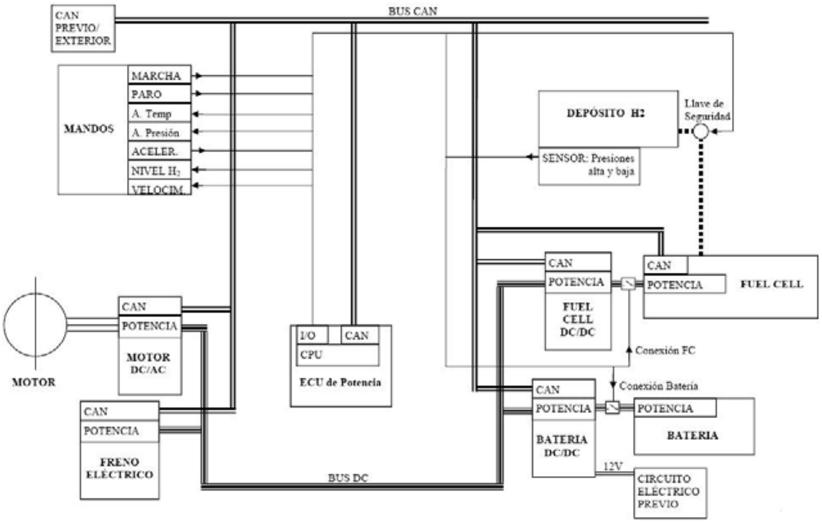

Figure 4 - Control system general scheme

On the other hand, the vehicle has a supervision system, independent of the ECU, which monitors the different interesting variables for the user. If the ECU is a vital system for the operation of the vehicle, the supervision system is only used to observe or store historical data of the behaviour of the vehicle. The system has been mounted in a PC adapted to operate in vehicles (PC-Car) and the chosen software is Labview.

3.6. Hydrogen storage system design

To calculate the amount of hydrogen needed to satisfy the range requirements for the vehicle, that were of a minimum of 100 km, some simulations of consumption with ADVISOR (Advanced Vehicle Simulator) were done, reaching the conclusion that with a storage volume of 100 lwc, equivalent to about 3 kg of hydrogen at 350 bar, an average autonomy of 180 km in urban cycles, 130 in extraurban cycles can be reached. This 3 kg of hydrogen as well as the available place that implies volume, weight and size limitations of the commercially available cylinders, have been considered the reference to select the hydrogen cylinders to be mounted in the vehicle, able to operate with high pressure hydrogen, and that can be certified for their safe use.

In agreement with information compiled in diverse European projects, it has been verified that the most suitable option for its location in the vehicle is the rear part, behind the back seats, which is denominated “survival minimum space”, since it is the part less frequently affected by a severe shock and presents the smaller deformation energy.

The cylinders are located in the rear part of the vehicle, placed horizontally, cross-sectional form to the axis of the vehicle. This location have also conditioned the maximum diameter and length of the cylinders, because to fit this place the maximum length of each cylinder plus the safety valve installed in its outlet, cannot exceed 1000 mm.

Finally, the system consists of three type III hydrogen storage cylinders, one of 26 lwc and two of 34 lwc (geometric capacity), with a total volume of 94 lwc, and a storage capacity of 2.3 kg of hydrogen at 350 bar. For this storage capacity, the average range in urban cycles is 140 km, and 101 km in extraurban cycles.

The specifications of these cylinders are:

- Model: L034H350G8
    - Volume (l): 34
    - Working pressure (bar): 350
    - Nominal diameter (mm): 280
    - Nominal length (mm): 830
    - Weight (kg): 17.6

- Model: L026H350G8
    - Volume (l): 26
    - Working pressure (bar): 350
    - Nominal diameter (mm): 280
    - Nominal length (mm): 655
    - Weight (kg): 14.1

Each cylinder has a solenoid valve in one of the outlets with pressure and temperature sensors, pressure relief device (PRD) and manual valve connected to it.

In the refuelling line it is located an anti-return valve, to avoid that, in normal operation, the gas can leave by the refuelled line. Next a pressure gauge to verify “in situ” the cylinders load pressure, and finally, the receptacle that matches with the corresponding refuelling stations’ nozzle.

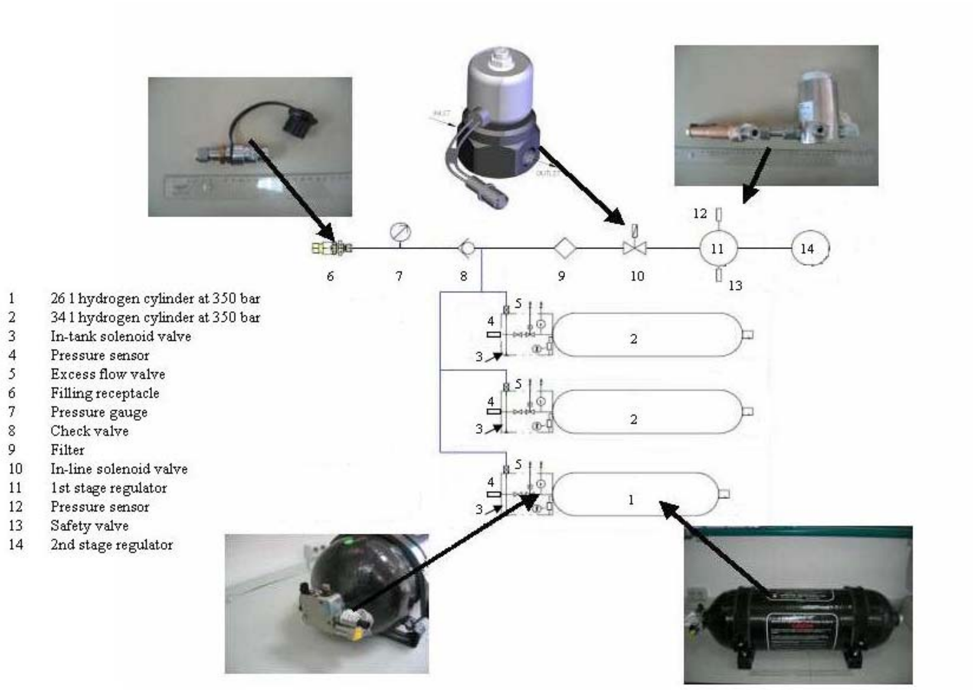

Figure 5 - Hydrogen storage system diagram.

In the line that connects the cylinders to the fuel cell, there is a filter to eliminate the possible particles that can be introduced in the system during the refuelling process, coming from, for example, the dust placed on the connectors surface, and after this filter a solenoid valve, redundant to the ones located at the cylinders' outlets, to assure the disconnection between the cylinders and the fuel cell entrance when needed, and a two-stages regulation system to decrease the hydrogen pressure to the fuel cell inlet pressure. In case of overpressure, the regulation system is connected to a safety valve, so that if, by some circumstance or failure, the outlet pressure of the regulation system is higher than a set pressure, the hydrogen is vented in a controlled way, avoiding damages to the fuel cell entrance.

4. Future tasks:

After the construction of every system, each one is being characterized separately and integrated in a test bench to evaluate the operation of the complete system and determine if any component needs to be redesigned before the integration in the chassis of the prototype.

It is expected that on 2009 the systems will be integrated in the vehicle, so that it can be tested in trial tracks under different conditions of operation, and in test benches to determine conditions of operation in diverse urban and combined standard driving cycles. Depending on the tests results, some systems could be redesigned and the vehicle could be modified.

Finally the prototype will begin operating at the solar hydrogen refuelling station that is being developed in “Las Columnas” subproject.

5. Acknowledgements:

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