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Development of LPI Hybrid Electric Vehicles

- From Mild to Full Hybrids

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Abstract

The global issues of air pollution and fossil fuel shortages have dramatically created the demand for eco-friendly vehicles. The need to be socially responsible and to preserve the environment has driven Hyundai-Kia to make every effort to develop Hybrid Electric Vehicles and demonstrated leadership on the environmental technology as one of the most advanced vehicle manufactures in the world. Getting started with the Sonata electric vehicle in 1991, Hyundai-Kia Motors has studied the technologies of the environmentally friendly vehicle including electric motors, batteries, and controllers. As a result, based on these technologies, Hyundai-Kia Motors has been in the competitive position to develop its own hybrid electric vehicles. The hybrid compact sedans - Accent(Hyundai) and Rio(Kia) have been developed based on Gasoline Hybrid technologies. The Accent/Rio Hybrid have a flywheel mounted MG (Motor-Generator) type parallel hybrid system. Ever since hundreds of Accent/Rio Hybrid were supplied to Korean Ministry of Environment in 2005, the performance related to fuel economy, emissions, drivability has been improved continuously and thousands of HEV's are being supplied as official vehicles of Korean Government since 2007. The accumulated technologies related with HEV have been welded into LPI engine technologies and the blending of these two technologies has made Hyundai-Kia Motors create unique hybrid system – LPI hybrid system. To improve the LPG fuel economy without deteriorating performance and value of the vehicle, various technologies have been developed and adopted. As a result of the component technology and system optimization, LPG fuel economy has been improved. The Elantra LPI HEV will be launched this summer as a mild hybrid and the Sonata LPI HEV is under developing as a full hybrid.

Keywords: HEV(hybrid electric vehicle), parallel HEV, lithium battery, ICE (internal combustion engine).

1 Introduction

Currently, growing environmental and economic concerns - caused by air-pollution, global warming, and limited amounts of fossil fuels - have led automotive companies to spare no efforts to produce advanced vehicles with high fuel-efficiency and low emissions. Automotive companies have conducted research and developed alternative drive-trains in addition to conventional measures like decreasing weight and reducing air / rolling drag coefficients. Electric Vehicles (EVs), Hydrogen-driven engines, Hybrid Electric Vehicles (HEVs) and Fuel Cell Vehicles (FCVs) are being examined as alternative drive-trains developed to meet strict regulations on fuel economy and emissions. [1)] Among them, HEVs are the most promising in terms of competitive fuel economy ratings, and have already proved to be an acceptable market solution for the customers.

Hyundai-Kia have made a major effort to develop practical HEVs and bring them to market as soon as possible. Hyundai-Kia chose a Liquefied Petroleum Injection (LPI) HEV as the first HEV for the Korean market since the customer's critical concerns are fuel expense and less emission level rather than gas mileage itself. In Korea, the price of LPG is almost half that of gasoline and the gas mileage of an LPG vehicle is generally about 80 percent of a comparable gasoline vehicle's mileage. Therefore, an LPG HEV is more economical to operate than a gasoline HEV and other types of hybrid vehicles currently available in the market. Also, LPG has an advantage over gasoline in terms of CO_2 emissions. In the following sections, HEVs from Hyundai-Kia will be introduced in detail, especially the LPI Hybrid.

Table1: Characteristics comparison of fuels*

Fuel		Gaso-line	Propane	Butane
Liquefied density [*kg/l*]		0.72 ~0.77	0.50	0.58
caloric value	[*MJ/kg*]	43.0	46.3 (7.6%↑)	45.7 (6.3%↑)
	[*MJ/l*]	33.3	23.2 (30.3%↓)	26.5 (20.4%↓)

*Automotive LP Gas 3rd Edition, World LP Gas Association

Table2: Fuel expense comparison*

	Mild LPI HEV	Civic HEV	Prius
Gas mileage [*km/ℓ*]	17.2	23.2	23.7
Fuel expense/yr [10000KRW]	88	112	110
Additional fuel expense [10000 KRW]	base	+24	+22

*based on 17,000 km/year annual mileage
*based on the fuel price from Korea Petroleum Association (4th week, March 2009) : Gasoline=1,528 KRW, LPG=894 KRW.

2 LPI Full Hybrids

Development of Hyundai-Kia's very first HEV dates back to the 1990s. In 2004, the Getz gasoline Hybrid was developed and 50 vehicles were supplied to Korean Ministry of Environment as part of a demonstration fleet. With the experience of Getz Hybrid, the technology development of the gasoline hybrid system continued to expand and was applied on compact cars (Hyundai Accent Hybrid and Kia Rio Hybrid). In 2005, 350 HEVs were supplied to the Korean Government and added to the demonstration fleet. In the second stage of the Accent/Rio Hybrids, the performance related to fuel economy, emissions, and drivability have been improved, and thousands of HEVs have been provided to the fleet in 2006 and 2007. The accumulated hybrid technologies have been welded into LPI engine technologies and the world first Elantra/Forte LPI hybrids are going to be launched this summer as a mild hybrid. Also, Sonata LPI hybrid is being developed as a full hybrid.

2.1 System Architecture

The Sonata LPI Hybrid is a parallel type hybrid electric vehicle. In details, it is TMED (Transmission Mounted Electric Drive) type hybrid with an engine clutch as shown in Fig. 1. It is composed of several main components: engine, 6-speed automatic transmission, electric motor, hybrid starter generator (HSG), hybrid power control unit (HPCU), battery, and electro-hydraulic brake (EHB) as shown in Fig. 2. The vehicle incorporates two different propulsion systems to deliver power to the wheels; a conventional internal combustion engine and a synchronous AC motor.

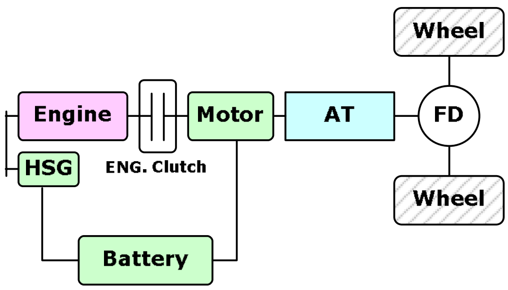

Figure1: Hybrid system configuration

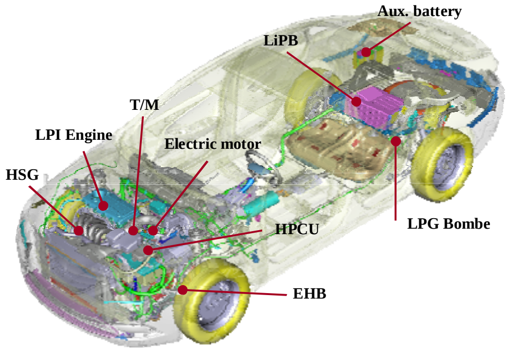

Figure2: Major components of the Sonata LPI HEV

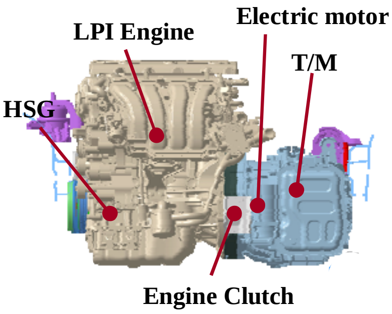

Figure3: Hybrid power-train

These components are located in the engine room. Fig. 3 shows the hybrid power-train which is composed of the engine, engine clutch, electric motor, HSG, and 6-speed A/T. As the vehicle's electric energy storage system, LiPB (Lithium-ion Polymer Battery, Li-Poly battery) is located in the rear side of the vehicle, under the trunk compartment. The HPCU is placed by the side of A/T.

2.2 LPI Engine

Even though electric components like the motor and the battery are important in hybrid electric vehicles, the engine plays the most important role in achieving competitive fuel economy. Therefore, significant efforts have been made to develop the engine for Sonata LPI Hybrid. Engine specifications are shown in Table 3. Some modifications were made to improve fuel efficiency, especially reducing the power rating of the engine. To increase thermal efficiency, the Atkinson cycle is employed and the compression ratio is increased. To increase mechanical efficiency, the valve spring load and piston ring tension were reduced. Also, dual-CVVT (Continuously Variable Valve Timing) and ETC (Electronic Throttle Control) were applied.

Table2: Engine specifications

Engine Type	ν - 2.0 LPI DOHC 4-Valves
Power/Torque	137PS/17.7kgf-m
Emission	SULEV
Features	Atkinson cycle Dual CVVT High compression ratio Low valve spring load Low piston ring tension

2.3 Transaxle

The 6-speed automatic transmission is used for the Sonata LPI Hybrid and an engine clutch is installed instead of a torque converter for better fuel economy. Fig. 4 represents the section view of the transaxle in the Sonata LPI Hybrid. The torque capacity is 27.1 kgf-m and an electric type oil pump is installed on it for low speed range.

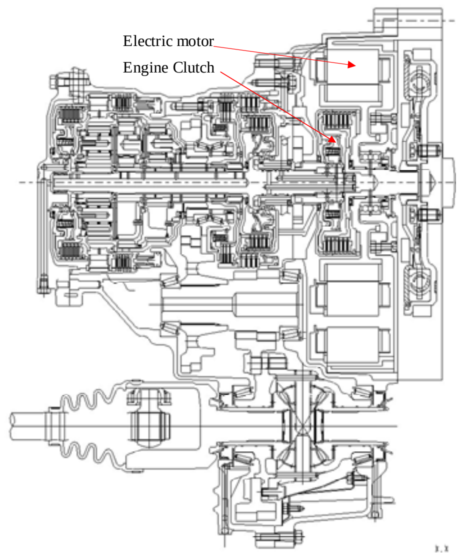

Figure4: Section view of T/M

2.4 Electric Motors

There are 2 electric motors in this hybrid power-train. The one is the electric motor and the other is HSG. The electric motor is a pancake type IPMSM (Interior Permanent Magnet Synchronous Motor) installed between the engine and the transmission. The IPMSM includes a resolver type position sensor, from which the HPCU receives the position of the motor rotors. Fig. 5 shows an exploded view of the electric motor, the engine clutch and the transmission. Maximum power and torque are 30kW and 205Nm, respectively. The magnet shape

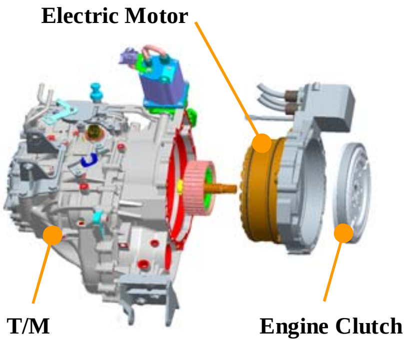

Figure5: Exploded view of the electric motor assembly

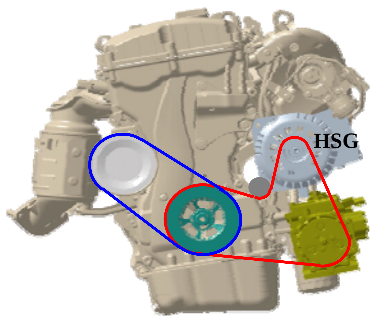

Figure6: Configuration of HSG

and arrangement of the motor ('gull-wing' type) is optimized for better performance. It is cooled by ATF of the transmission. HSG is cylindrical type IPMSM and connected to the engine through the belt as shown in Fig. 6. Maximum power and torque are 5.6kW and 43.2Nm, respectively. It is cooled by water.

2.5 HPCU

HPCU is an integrated type unit. It can control 2 motors at the same time and supply electric energy to 12V auxiliary electric load. Also, it manages power distribution strategy for hybrid power-train. It has the motor control unit (MCU) for the electric motor, the MCU for HSG, DC/DC converter for 12V auxiliary electric load, and HEV control unit (HCU) as shown in Fig. 7.

2.6 Battery

A Li-Poly-type battery is used for Sonata LPI Hybrid. Fig. 8 represents the outline of the battery system. It has its own (Li-Poly battery pack), Battery Management System (BMS), Power Relay Assembly (PRA), and forced air cooling system. It operates at the nominal voltage, 270V and the capacity is 5.3Ah. The basic function of the battery system is to store in chemical form, electric energy obtained either from the engine or regeneration and supply the stored energy as needed. Additionally, it has to manage input and output power based on the State-Of-Charge (SOC). For safety, by controlling the battery temperature within an allowable range the battery is prevented from melting or explosion. The main design criteria for the battery system are power, energy density, and durability. To achieve better performance in these three criteria, the BMS performs accurate estimations of battery status and controls temperature appropriately.

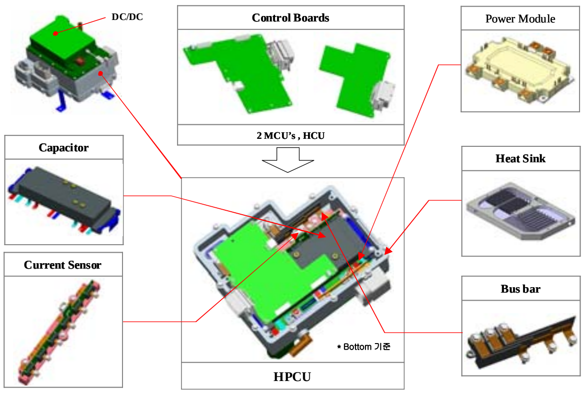

Figure7: HPCU

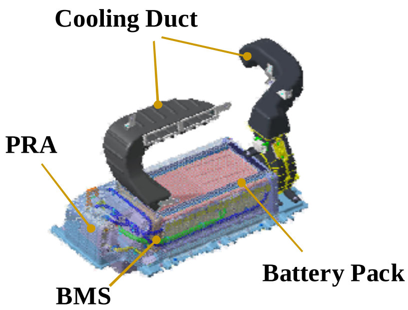

Figure8: Battery system

3 Conclusion

The full hybrid from Hyundai-Kia is LPI HEV because the product concept of it is 'less fuel expense and less emission'. The Sonata LPI Hybrid as a full hybrid is based on a TMED type parallel hybrid system. Hyundai-Kia have succeeded in realizing continuous improvements in fuel economy, emissions and drivability since mild LPI hybrid. Developing this Sonata LPI hybrid, Hyundai-Kia have the capability to make a full line-up of LPI HEV from mild to full

References

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