HMC's Strategy for Future Powertrain with Refined and Confident Innovation

Seong-Hyon Park
Power Train R&D Center
Corporate Research & Development Division, Hyundai·Kia Motors
772-1, Jangduk-Dong, Hwaseong-Si, Gyeonggi-Do, 445-706, Korea

Today's global automotive industry has confronted stricter demands of many different circumstances. One of the most challenging tasks for automakers in the future is the efficient use of promising new technologies that are not only saving the energy resources but beneficial to humanity. In order to meet such challenges, Hyundai Motor Company (HMC) is concentrating its efforts on innovative development of advanced technologies which are related to the reduction of exhaust emission and fuel consumption, ultimately applicable to hybrid electric vehicles.

***Keywords*: Powertrain, Gasoline, Diesel, Fuel Consumption, Exhaust Emission, Hybrid Electric Vehicle, Alternative Fuels**

1. INTRODUCTION

The crude oil price has been nearly doubled during the last two years, and consequently the prices of gasoline and diesel fuels are breaking the records day by day. Especially with the global movement to regulate the CO_2 emission as shown in Fig. 1, the automotive companies are under increasing pressure to provide useful solutions for reducing the fuel consumption. In order to meet the 120g/km CO_2 emission by 2012, break-through technologies must be introduced to the automotive industry.

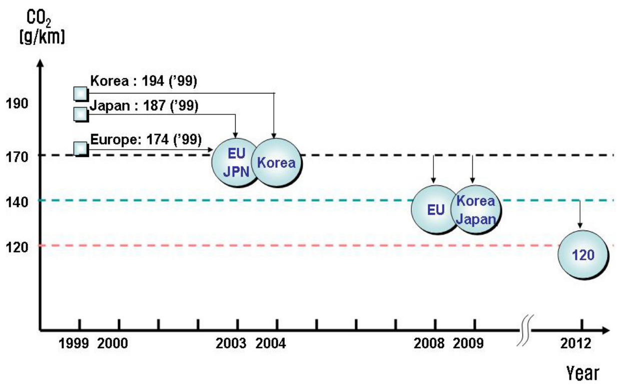

Fig. 1 CO_2 Reduction Plan of ACEA

Furthermore, other emission regulations, such as California's PZEV and EU's Euro-V, require more and more complex and expensive technologies. Therefore, in order to produce competitive vehicles in the market, the global R&D efforts for developing the emission reducing technologies are increasingly important.

Our efforts can be grouped to two different approaches: 1) Improve conventional powertrain such as gasoline or diesel fuel based engines by applying innovative technologies; 2) Apply alternative approaches such as hybrid electric vehicles (HEV) and compressed natural gas vehicles (CNGV). Before the electric vehicles based on fuel cells become dominant, IC engines operated by alternative fuels and hybrid electric vehicles will still serve the major role as the automotive power source for years to come.

2. R&D STRATEGIES FOR FUTURE POWERTRAIN

Fig. 2 summarizes the core technologies that are capable of improving the fuel efficiency. Gasoline engines have evolved to overcome their shortcomings, such as the large pumping loss and low thermodynamic efficiency, by adapting variable mechanisms and advanced combustion control strategies. HMC mass-produced lean-burn engines in 1997 and currently is applying the continuous variable valve timing (CVVT) system to the majority of engines produced. HMC is developing improved valvetrain systems by applying variable valve lift (VVL) and cylinder deactivation (CDA) concepts, and also investigating advanced combustion concepts, such as gasoline direct injection.

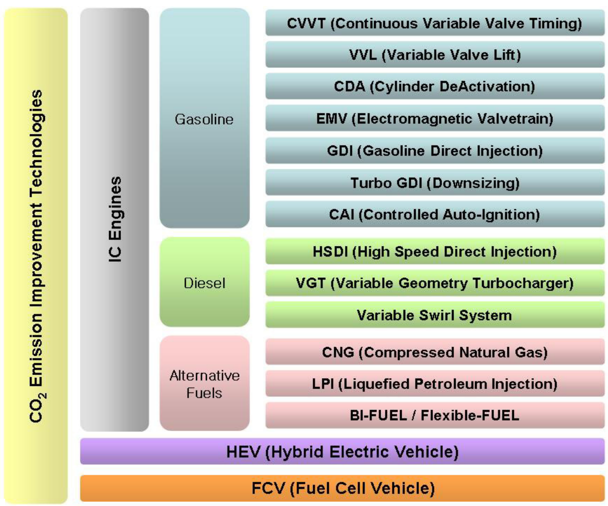

Fig. 2 Technical Recipe for CO_2 Emission Improvement

Especially, the continuous variable valve lift and electromagnetic valvetrain will be the technologies that would eliminate the throttling losses in gasoline engines completely. In the combustion control side, the gasoline direct injection and controlled auto ignition (CAI) are the promising technologies that would significantly improve the thermal efficiency. Even though the engines with intake boosting such as turbo- and super-charging are not new concepts, these ideas are highlighted in another prospective, the downsizing for the fuel-efficiency improvement. The major reason for the improved efficiency in the boosted engines is the reduced pumping loss and friction due to the smaller displacement.

Meanwhile, the major challenge for diesel engines is to reduce the NO_X and PM emissions to meet the emission regulations. HMC's approach towards the improved diesel engines can be summarized as applying the following technologies: 1) Electronically controlled high speed direct injection based on the common rail fuel system for accurate fuel injection and combustion control; 2) Variable geometry turbocharger (VGT) for improved performance and reduced emission; 3) Electronically controlled cooled EGR system for reduced emission; 4) Variable swirl sytem; 5) Diesel Particulate Filter and other combinations of advanced after-treatment technologies.

Recently Hybrid Electric Vehicle (HEV) is gaining an increasing attention as a strong candidate for next generation vehicle. Thanks to the motor assist and regeneration of energy, HEV's show great improvement in fuel-efficiency, while exhaust emission can be remarkably reduced compared to the vehicles with SI engine.

Due to the abundance and clean combustion characteristics of some alternative fuels, such as compressed natual gas, liquefied petroleum and bio-fuels, they have been considered as promising alternatives over the conventional liquid fuels. Consequently, IC engines using alternative fuels such as compressed natural gas (CNG) and liquefied petroleum are also considered as strong candidates for clean powertrain.

2.1 Gasoline Engine Technologies

Hyundai, DaimlerChrysler and Mitsubishi Motors are under a unique three-way partnership, Global Engine Alliance. It aims to supply the θ engine that was designed and developed by HMC as the powertrain for the next generation mid-sized vehicles of three partner companies. This alliance creates "economies of scale" benefiting the sharing of key technologies, joint sourcing and most importantly significant reduction in the engine development costs. The scale of the global engine program will reach two or more million engines, making it the world's largest passenger car engine program.

Type	I-4, DOHC 4 Valves
Displacement	2,359 cc
Bore x Stroke	88mm x 97mm
Dry Weight	130.0 kg
Max. Power	166 PS
Max. Torque	23.0 kg.m

Fig. 3 θ engine

The θ engine produces world-class performance and fuel-efficiency thanks to the various advanced technologies such as CVVT and the application of timing chain system. According to the 2006 MY Fuel Economy Guide of EPA, Hyundai Sonata driven by the θ-2.4L engine was chosen as the most fuel-efficient model in the Large Car segment.

Following this path, HMC has prepared and developed various new technologies for innovative new products. Future engines will be developed based on these efforts to meet customer and environmental requirements. The followings summarize HMC's activities and development directions for the future gasoline engines.

2.1.1 Variable Valve Lift (VVL)

One of the most successful strategies to improve the fuel efficiency in gasoline based spark-ignited engines is to reduce the throttling through various mechanisms. Among those strategies, VVL is known as a technology which could eventually lead to a completely unthrottled operation. In VVL, both lift and duration of valve profiles can be switched or continuously varied by using various hardwares.

There are several strategies applied in VVL systems. Traditionally, VVL has been applied to enhance the volumetric efficiencies in high-revolution engines while maintaining low-speed stability. VVL could also be used to obtain improved cold starting characteristics with reduced catalyst light-off time.

In engines with sufficient driving torque, extremely low lift profiles can be applied during partial load conditions to minimize pumping loss and thus improve fuel efficiency. Fig. 4 shows a typical VVL system applied in a swing arm type valvetrain. In this system, friction is reduced by the roller contact during partial load conditions.

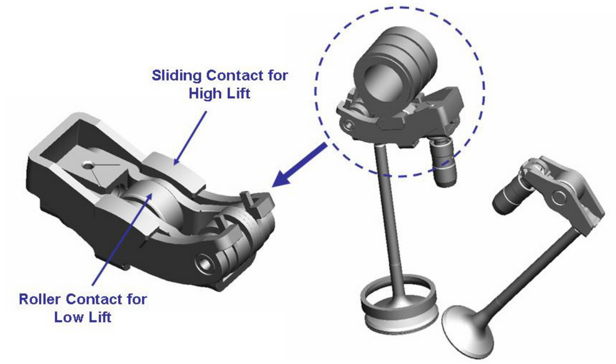

Fig. 4 VVL System in a Swing Arm Type Valvetrain

In HMC, both discrete multi-step VVL and continuous VVL technologies are being investigated in gasoline engines. Our investigations show that as much as 5% reduction in fuel consumption could be achieved in partial load conditions with improved emission characteristics. HMC will be applying both discrete multi-step and continuous VVL to improve the fuel efficiency, while satisfying the performance and emission requirements.

2.1.2 Gasoline Direct Injection

The Gasoline Direct Injection engine has been established in

Europe and Japan as a fuel economy concept by applying lean operation in partial load by means of so-called stratified charge operation. Such lean stratified gasoline direct injection concepts require an extra DeNOx catalytic converter in the exhaust system to effectively treat NO_X emissions that are being generated in the engine due to the presence of excess air during combustion. Furthermore, in order to meet the emission regulations, the fuel efficiency benefit of lean stratified gasoline direct injection concepts decreases, which resulted in the contraction of volume in the market.

We investigated both stratified and stoichiometric versions of gasoline direct injection. Especially, the stoichiometric version of gasoline direct injection could be applied to improve the light-off of the catalytic converter, which could significantly improve the emission characteristics compared to the base port fuel injection engines. Stoichiometric version can dispense with the DeNOx catalytic converter for NO_X. In addition, the stoichiometric gasoline direct injection shows potential for enhanced fuel economy and at the same time fulfills demands for higher specific power output over conventional SI engines. The compression ratio can be slightly increased without exceeding the knock limit because of the internal cooling effect of directly injected fuel in the cylinder. Fig. 5 shows the section view of a gasoline direct injection engine with a tumble control mechanism.

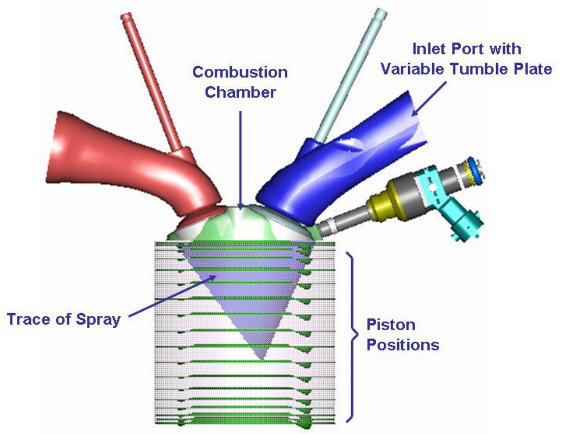

Fig. 5 Combustion Chamber for Gasoline Direct Injection

Recently, boosting technologies in combination with gasoline direct injection and CVVT came to our focus as the downsizing concept. With gasoline direct injection, CVVT can be effectively applied to boosted engines, while maintaining the compression ratio similar to NA engines. This configuration improves the transisent response of turbocharged engines, and thus more aggressive downsizing would be possible.

2.1.3 Cylinder DeActivation (CDA)

In many driving circumstances, the entire torque of a multi-cylinder engine is not required. Especially for engines with sufficient torque with large displacement or with electric motor support, improved efficiency could be realized by running the engine with some cylinders deactivated in partial load conditions. The improved efficiency could be achieved by deactivating the valves of some cylinders, and thus reducing the throttling of the engine. Fig. 6 shows one of the cylinder deactivating strategies that can be applied to V8 engines. In our investigation of a CDA system, we could achieve more than 15% reduction in fuel consumption in partial load conditions.

In order to realize a cylinder-deactivation system, proper valve deactivating mechanisms and advanced control strategies during the activation/deactivation transitions are required.

The CDA concept can effectively be applied to V6 engines and to powertrain for a hybrid electric vehicle. The combined use of VVL and CDA is also being investigated to maximize their respective benefits.

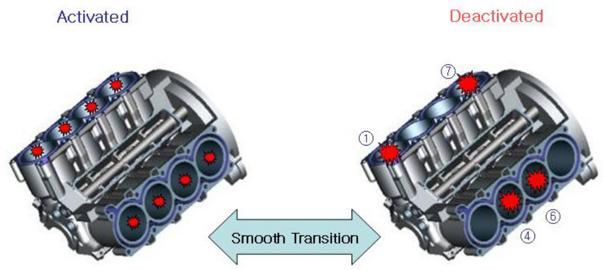

Fig. 6 Cylinder Deactivating Strategy in V8 engines

2.1.4 Electromagnetic Valvetrain (EMV)

Since 1998 Frankfurt motor show, EMV (Electromagnetic Valve Train) has been regarded as an ultimate valvetrain solution with great freedom in the valve timing and duration control. There have been significant improvements in EMV area during last years, and recently Honda and Valeo developed EMV systems that are applicable in advanced combustion control scheme, such as CAI. HMC had completed an EMV development project, and more than 15% improvement in partial load fuel efficiency and 10~20% increase in low speed torque were found. However, a few problems, such as reliability, excessive valve driving energy and NVH, were observed. From the results of the EMV investigation, HMC made efforts to realize the known benefits of EMV by means of mechanical systems such as Intake/Exhaust CVVT, CDA, VVL and CAI.

With great progresses in power electronics parts, such as permanent magnet combined actuator, intake-only EMV, compact actuator, high-efficiency generator and DC-DC converter, EMV becomes a more feasible technology. With these solutions, HMC will be developing and applying EMV to future powertrains.

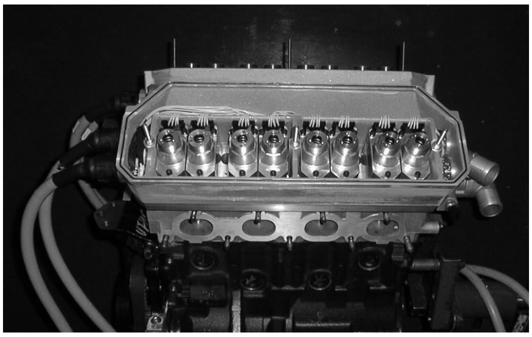

Fig. 7 EMV System assembled in an Engine

2.1.5 Controlled Auto Ignition (CAI)

Auto-ignition in a gasoline engine had been recognized for abnormal combustion phenomenon. Recently, Controlled Auto-Ignition, which is known as CAI or HCCI, became a feasible and environment-friendly technology thanks to the technological achievement in the intake air control, internal EGR control and compression ratio control.

Different from the conventional SI engines, CAI engines utilize compression ignition concept similar to the Diesel engines. Because of that, it has high potential for both fuel economy and NO_X Emission reduction.

HMC recently developed single cylinder CAI engine equipped with direct fuel injection system. The test results achieved from the CAI engine show up to 15% reduction in fuel consumption and up to 98% reduction in NO_X emission. CAI combustion can generally be realized using either internal gas fraction control or compression ratio control. HMC applied the internal gas fraction control scheme, which can be realized using variable valve actuators.

By applying CAI, various benefits are expected besides the reduced fuel consumption and emission. Some of the examples are flexible fuel concept, use with motor assist (HEV) and combination with boosting. HMC is planning to pursue more investigation in those areas.

2.2 Diesel Engine Technologies

2.2.1 High Speed Direct Injection (HSDI) Engines

The high speed direct injection (HSDI) based on the common rail fuel system revolutionized the performance and exhaust emission of Diesel engines. Specific power of Diesel engines is surpassing gasoline engines while retaining the fuel-efficient characteristics from the unthrottled and high compression-ratio operation. It is also the most likely candidate to satisfy the 140g CO_2 emission goal of year 2008.

In common rail HSDI systems, fuel is pressurized up to 1800 bar, and the injection is accurately controlled by the solenoid or piezo type injectors. Multiple injection schemes, such as post injection and multiple pilot injections, are applied in order to reduce the PM emission and to obtain best combustion noise level.

We are mass-producing Euro-IV capable U, D, A and J engines with the common rail HSDI system. They are applied to the broad model lineup ranging from the compact sedan, Hyundai Accent, to the full-size SUV, Kia Sorento, as shown in Fig. 8.

Fig. 8 Examples of Model Lineup with HSDI Diesel Engines

2.2.2 Selective Catalytic Reduction (SCR)

In order to achieve clean diesel based engines, it is essential to reduce the level of PM and NO_X emission. Diesel Particulate Filter (DPF) has been already developed and introduced in the market for PM reduction purposes. DPF system requires regeneration events and accurate soot monitoring system. For further reduction of the exhaust emission, NO_X reduction devices are being developed. Urea SCR system shows conversion efficiencies up to 70 to 90% in broader temperature range compared to other NO_X aftertreatment systems.

Due to the complexity of the system, typical Urea SCR systems are mainly installed into the commercial vehicles rather than to passenger cars. In addition, Infrastructure for Urea delivery and solutions to prevent ammonia slip is required for the wide-spread application of the system.

2.2.3 Achieving Euro-V

The reinforced Euro-Ⅴ standards are proposed to an 80% reduction in PM and a 20% reduction in NO_X emission compared to the current Euro-Ⅳ standards. Major modifications required to achieve Euro-V are summarized in Table 1. The standard combination to achieve Euro-V standards include a DPF system for PM reduction, reduced compression ratio for lower combustion temperature and inclusion of a Diesel Oxidation Catalyst (DOC) to suppress HC and CO emission due to the reduced combustion temperature.

Table 1 Major Modifications to achieve Euro-V

System	Baseline Euro-Ⅳ	Proposed Euro-Ⅴ
Combustion System	17.3:1 Comp. Ratio 150bar Pmax	16-16.5:1 CR Advanced glow plugs
Inlet Ports	R_S 1.4~3.0	Swirl potentially revised
Intake Manifold & EGR Distribution	Variable Swirl	Variable Swirl system Improved EGR variation
Injection System	1600bar Solenoid CR	1800bar Piezo CR
Turbocharger	Baseline	Revised boosting & EGR
EGR	Cooled EGR with no bypass	Increased EGR cooling Bypass temp. control
Control Strategy	Baseline	Advanced EGR & Boost Control algorithms
DOC	Euro-Ⅳ Diesel Oxi-Cat.	Advanced CC DPF with Oxi-Cat

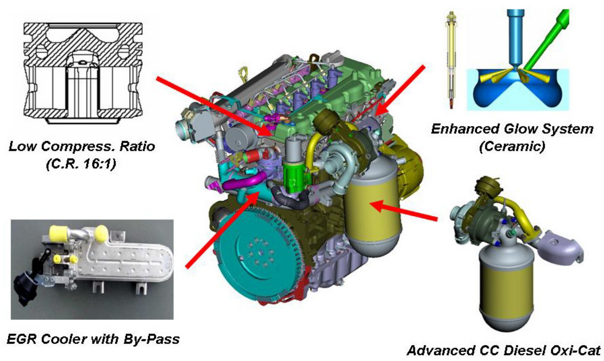

Fig. 9 Main Features of Euro-V System

To enhance NO_X and PM reduction, improved cooling efficiency of the EGR system and the minimized deviation of the EGR distribution between each cylinders are required. In the control side, the model based control concept are being introduced to improve the transient characteristics. Accomplishment of Euro-Ⅴ emission standards will be possible from the optimization of these technologies. Fig. 9 shows an Euro-V capable configuration developed in HMC.

2.3 Hybrid Electric Vehicle (HEV)

In 1995, we developed a serial type HEV with Ni-MH battery and 0.8ℓ gasoline engine aiming to produce similar driving range to normal gasoline engine powered vehicles. Starting with the small-quantity production of Click HEV's in 2004, Pride HEV's are produced to verify the developed technologies. The basic elements of a Click HEV are shown in Fig. 10. We are planning to mass-produce HEV's satisfying the SULEV regulation in the near future, and believe that they could be an excellent substitute over pure electric vehicles.

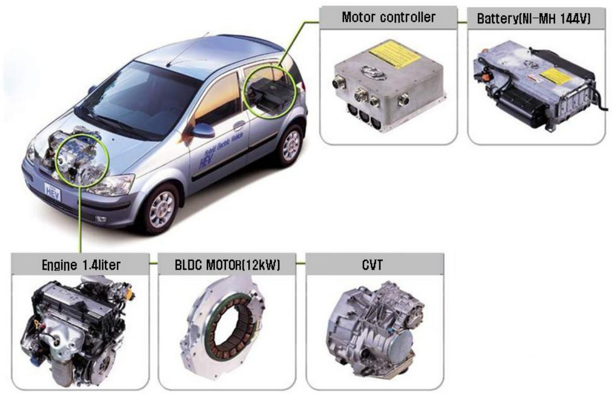

Fig. 10 Configuration of Click HEV

The engines specifically developed for an HEV have two different characteristics compared to the existing gasoline engines: 1) higher efficiencies; 2) lower friction loss. The engines for HEV's can be developed with more degrees of freedom focusing mainly on fuel efficiency. Idle stop, Cylinder deactivation in 4 cylinder engines for the increased regeneration efficiency and other engine friction reduction technologies, such as the coating on the various surfaces using physical vapor deposition (PVD), can be good examples applicable to HEV's.

2.4 Alternative Fuels

2.4.1 CNG engines

During the early 90's, HMC developed compressed natural gas (CNG) engines, and they are now widely used as the powertrain for buses in metropolitan area. With CNG engines, similar efficiencies to gasoline engines are achievable with lower CO_2 emission. However, due to the gaseous physical state and lower energy density, a high pressure storage is required in order to obtain reasonable driving range. In addition, the infrastructure for the high pressure natural gas stations should be prepared before the wide-spread use of the CNG vehicles. Fig. 11 shows a CNG engine powered bus developed in HMC.

Recently, the improved CNG engines for passenger vehicles are under development in path to reduce CO_2 emission and to achieve environment-friendly vehicle. Especially, high octane value of natural gas could be synergetically combined with the boosting concept to enhance the efficiency.

Fig. 11 CNG Bus

2.4.2 LPI engines

Liquefied Petroleum Injection (LPI) engines are major improvements over the conventional LPG (Liquefied Petroleum Gas) engines with evaporator and mixer. HMC has mass-produced the first LPI vehicle in the world, Grandeur XG, which overcomed the shortcomings of conventional LPG engines such as cold start problems and lower specific power. By applying LPI, reliable cold start can be achieved at temperatures as low as -25℃, and CO/HC emissions are reduced by more than 70% compared to the conventional LPG engines. The specific power is about 95% of the base gasoline engine, which is as much as 20% improvement over conventional LPG engines. Currently, Sonata Taxis in Korea are powered by the θ-LPI engine, and they have shown field-proven reliability and performance.

HMC is developing technologies for various alternative fuels such as methanol, ethanol and other bio-fuels to prepare for the future with the environment-friendly powertrain.

3 SUMMARY

Various efforts of HMC towards the development of innovative future powertrain are reviewed. Despite the relatively short history in automotive research and development area, HMC has been successful in applying new technologies to satisfy the customer needs. With rises in energy prices and increased competition in automotive area due to the excessive supply in the global market, the importance of developing fuel-efficient and environment-friendly powertrain units is higher than ever. In addition, the trends of future engines are high power density and comfortable drivability. HMC's strategies for future powertrain can be summarized as follows:

1) For gasoline engines, we will actively apply variable mechanisms and advanced combustion control strategies to overcome the large pumping loss and low thermodynamic efficiencies. In this path, HMC will be developing and producing the gasoline engines with various technologies, such as Variable valve lift, Gasoline direct injection, Cylinder Deactivation and

Electromagnetic valvetrain.

2) For diesel engines, various emission reduction technologies such as High speed direct injection based on the common rail fuel system, advanced Variable geometry turbocharger (VGT), Cooled EGR system, Variable swirl sytem, Diesel Particulate Filter and other combinations of advanced after-treatment technologies are applied in order to produce environment-friendly and fuel-efficient vehicles.

3) Alternative approaches, such as HEV, CNG and LPI engines, are also pursued to improve fuel efficiency and emission characteristics. HMC will be expanding researches on various alternative fuels, such as methanol, ethanol and bio-fuels to produce environment-friendly powertrain for the future.