THE NEW HYUNDAI-KIA 1.0 L THREE-CYLINDER GASOLINE ENGINE

With the new 1.0 l Kappa (κ) gasoline engine, which can be found in the face-lifted Hyundai i10 and the new Kia Picanto, Hyundai-Kia combines a three-cylinder concept with modern technologies such as the initial application of variable valve timing within this displacement segment. The derivate with switchable intake manifold delivers 60 kW/82 PS and achieves a maximum torque of 94 Nm. Next to the gasoline engine a bivalent version for the use of gasoline and liquefied petroleum gas (LPG) is already available; an ethanol engine is under development.

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CENTRAL ROLE IN THE COMPANY'S FUTURE SMALL CARS

Climate change and the influence of humans on it are the subjects of world-wide discussion. The transportation sector, including cars, trains, aircraft and ships, is responsible for more than one-fifth of all global CO_2 emissions. Hyundai-Kia is meeting the challenge to lower emissions as required by legislation in all markets. Such regulations, as well as rising energy prices, lead to an increased interest in compact vehicles. The new 1.0 l three-cylinder engine out of the Kappa family is part of the Hyundai-Kia sustainable product strategy and combines high achievement with fuel efficiency. The selected three-cylinder concept fulfils high acoustic requirements due to intensive detail optimization. From the beginning of development, the engine was designed with country-specific requirements in mind. The economic and eco-friendly Kappa engine family will – when flanked by additional derivates – take over a central role in the company's future small cars.

CONCEPT DECISION: NUMBER OF CYLINDERS

In the early phase of development, the four-cylinder engine was typical in the 1.0 l class. However, owing to increasing demands for improved fuel economy, three-cylinder engines were launched; the development of a two-cylinder engine was even reported. Friction loss and thermal efficiency are improved by reducing the number of cylinders. Therefore, determining the number of cylinders was crucial for development of the Kappa 1.0 l engine. Compared to a four-cylinder engine, a three-cylinder engine has better performance and fuel economy, ❶. Nevertheless, a NVH (noise vibration harshness) problem caused by increased unbalanced forces remained the weakness of the three-cylinder. However, through optimal design of the cranktrain, reinforcement of the engine structure and optimizing the match with a vehicle, NVH can be improved. Contrasting with a three-cylinder engine, a two-cylinder engine generally fitted to a motorcycle cannot meet NVH quality without a balance shaft because of excessive unbalanced forces caused by reciprocating mass. If the balance shaft is applied, the vibration of the C1 component will be decreased. However, fuel economy will become worse due to power loss. Also, applying a balance shaft increases cost and weight. Moreover, larger and longer intake and exhaust systems are necessary to reduce low-frequency combustion noise, the unique noise of a motorcycle. Even with the application of these technologies, there are limits to combustion noise reduction in a two-cylinder engine. Adding an alternator, air conditioner compressor and a starter motor on a two-cylinder engine body restricts design freedom. In conclusion, considering NVH quality, cost and other factors, the three-cylinder configuration was determined to best for the Kappa 1.0 l engine.

	4-CYLINDER	3-CYLINDER	2-CYLINDER
FUEL CONSUMPTION	Reference	+ (~ 3 % … 5 %)	+
PERFORMANCE		+	+
WEIGHT		+ (~ -10 %)	+
NVH		-	--
COSTS		+ (~ -9 %)	+
EFFECT OF SYNERGY*		+	o

*with κ 1.2 l four-cylinder

❶ Decision matrix: number of cylinders

VERSION	51 kW / 69 PS	60 kW / 82 PS	BIVALENT
NUMBER OF CYLINDERS [-]	3		
ARRRANGEMENT [-]	Inline		
DISPLACEMENT [cm³]	998		
BORE X STROKE [mm x mm]	71 x 84		
COMPRESSION RATIO	10.5		
DISTANCE OF CYLINDERS [mm]	78.5		
VALVE ARRANGEMENT [-]	4V – DOHC, Dual CVVT		
VALVE ACTUATION [-]	Tappet with mechanical lash		
TIMING DRIVE [-]	Roller chain		
INTAKE SYSTEM [-]	Fixed lenght	Variable length	
RATED POWER [kW]	50.7	60.3	
MAX. TORQUE [Nm]	95		
FUEL [-]	Gasoline		LPG / gasoline

❷ Engine specifications

SPECIFICATIONS

The new Kappa 1.0 l engine – DOHC with four valves per cylinder – achieves highest values for power, fuel efficiency and acoustics. The basic data of the aggregate are summarized in ❷. The engine design will be explained in the following paragraphs.

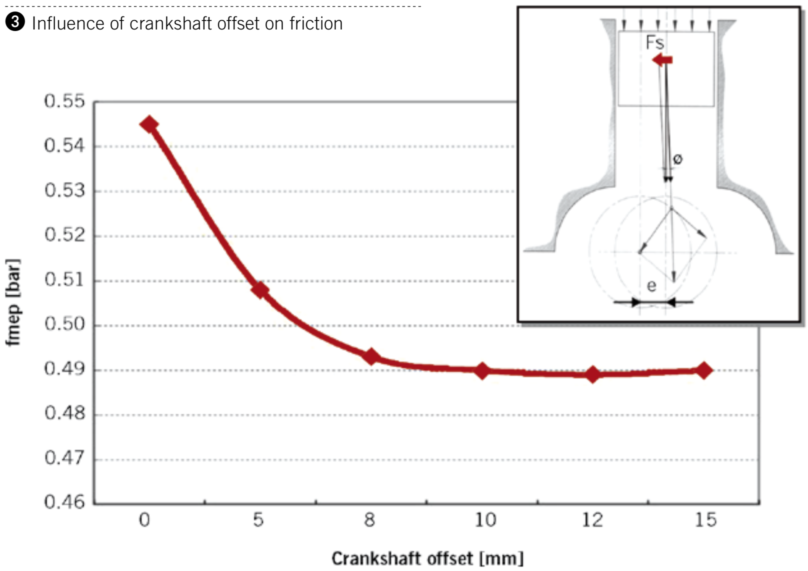
CRANKCASE

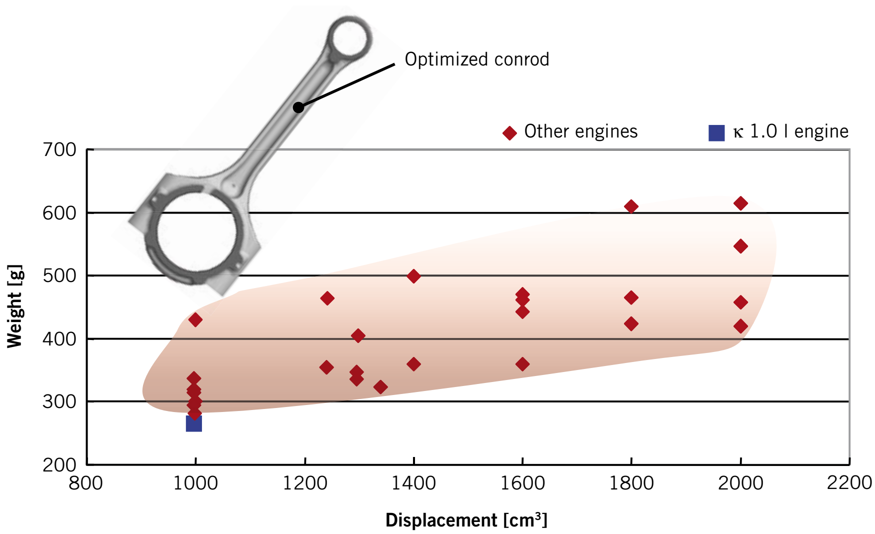
The aluminium alloy cylinder block is applied to reduce engine weight by 12 kg. Also, the cylinder block is designed as an open-deck type of high-pressure die-casting process. Meanwhile, to reduce the length and weight of the Kappa engine, the bore gap is designed to be 7.5 mm with a Siamese type. The cast-iron liner is applied to the cylinder bore to enhance the abrasion durability. With added 0.7 mm spine on the outer surface of the liner, adhesion between aluminium and the cast-iron liner is improved. Therefore, the deformation of the cylinder bore is reduced. Consequently, oil consumption and the amount of blow-by gas are decreased. The shape of the skirt is designed as a corrugated type to enhance stiffness. Also, for minimizing weight and improving NVH performance, the ribs and shape are optimized by FEM (Finite Element Method) analysis.

CRANKSHAFT AND PISTON GROUP

For reducing weight and manufacturing cost, the crankshaft is made of cast iron, FCD700C, and the shape of balance-weight is optimized by the cranktrain behaviour analysis to minimize three-cylinder engine vibration. In the case of the three-cylinder engine, the major design focus of the crankshaft is minimizing both the vertical pitching and longitudinal yawing. Both vibrations mainly depend upon the balance-weight and one is inversely proportionate to the other. Therefore, it is crucial to minimize the pitching and the yawing. By analyzing the crankshaft through dynamic simulations in the form of assembling pistons and connecting rods, the Kappa is designed to the optimal shape of its crankshaft balance-weight. The endurance of the crankshaft was ensured by computer-aided strength analysis and evaluating the physical part. To improve fuel efficiency, the offset crankshaft mechanism, ❸, is applied. The offset crankshaft mechanism is the fuel economy technology used to reduce the friction force between the piston thrust face and the cylinder bore inner face on the explosion stroke by optimizing the eccentricity e. But the contact force on a piston anti-thrust side becomes greater while a piston moves up. As a result of Computer-Aided Engineering (CAE) analysis, the eccentricity e is optimized at 11 mm, giving the Kappa improved fuel economy of 1 % at low engine speed. By using Design for Six-Sigma (DFSS) and FEM, the connecting rod is designed to be the lightest one in its capacity class, ❹, while improving fuel efficiency and ensuring endurance. In order to decrease the inertial force, the piston is optimized by minimizing the piston compression height (24.7 mm), pin-bosses distance and skirt length. As a result, piston weight is 161 g. Decreased weight of the piston and connecting rod enables the Kappa to improve fuel efficiency by about 0.5 %. Because the piston ring is coated with Physical Vapour Deposition (PVD), the tension of the piston oil ring is reduced by 33 %. MoS2-coated piston skirt and reduced piston ring tension provide 0.6 % better fuel efficiency to the Kappa. Two major technologies are applied on the bearings to improve fuel efficiency. First, the multi-boring bearing technology reduces oil leakage by eliminating the crush relief and optimizing the gap between crankshaft journals and bearings. Therefore, the optimized inner profile of the bearing decreases the amount of consumed oil. Second, the partially grooved bearing technology also reduces oil leakage by

❸ Influence of crankshaft offset on friction





❹ Optimized κ 1.0 l conrod in the field of competition

decreasing the grooved area of both ends. With these two technologies the oil pump capacity is decreased by 13 %, increasing fuel economy by about 0.4 %.

CYLINDER HEAD

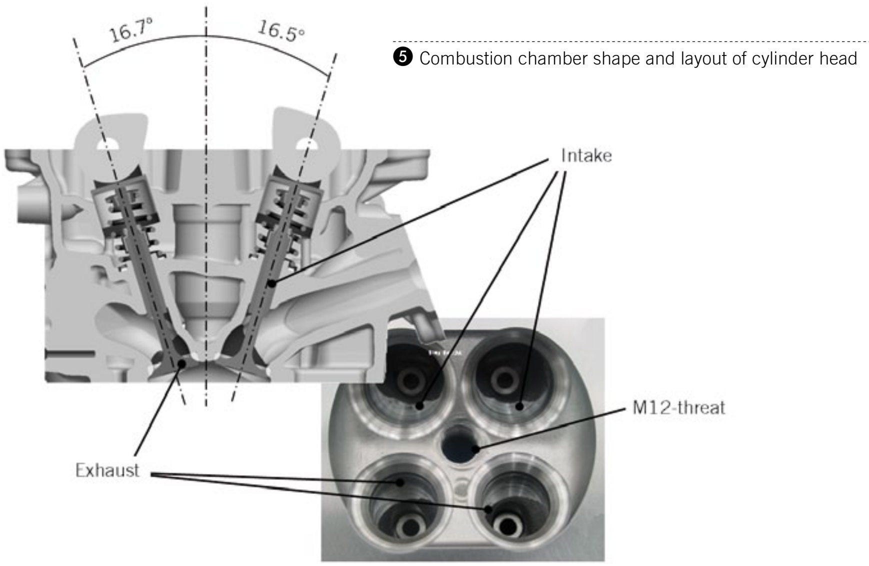
A pent-roof combustion chamber and a tumble inlet port, ❺, are applied to the cylinder head to reduce HC emission while improving the characteristics of combustion. Also, tumble flow, which was reinforced by 15.8 % than the initial design, was applied to improve combustion efficiency, therefore torque at low and middle speed (1500 to 3000 rpm) is improved by 1 %. For converging air-fuel mixture at the spark plug, the squish area takes 10 % of the cylinder bore area. The spark plug is placed in the centre to shorten flame paths thereby giving good combustion and reducing raw emission. The scissors angle of the valve was developed at 33.2 ° to minimize the surface of the combustion chamber, thereby improving combustion efficiency and minimizing the size of the cylinder head.

VALVETRAIN AND TIMING DRIVE

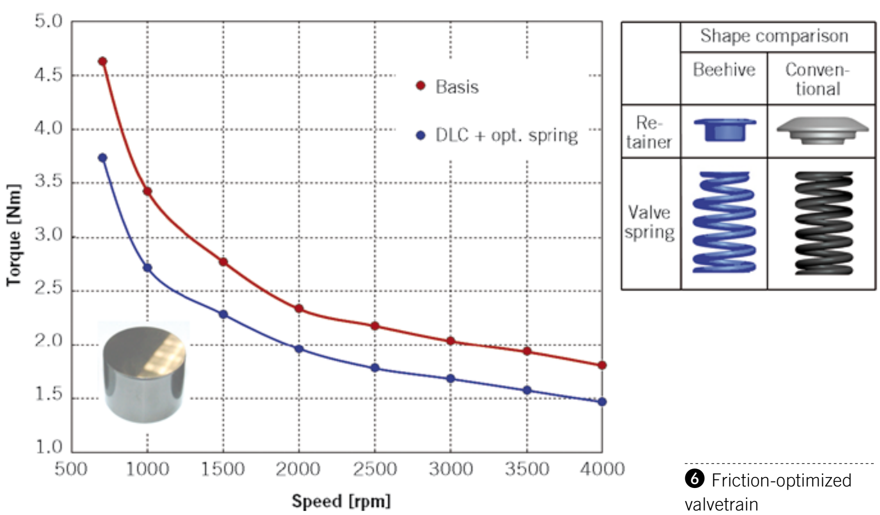
The Kappa adopts the world's first Dual Continuously Variable Valve Timing (Dual-CVVT) technology in its capacity class. Dual-CVVT technology maximizes fuel efficiency and performance by optimizing valve timing. It continuously alters inlet/outlet valve timing depending on driving conditions to reduce pumping loss and increase volumetric efficiency. With Dual-CVVT technology the Kappa improves fuel economy by up to 3 % and performance significantly compared to a non-CVVT engine. Also, it decreases emission gases such as NO_x and HC by the effect of the internal Exhaust Gas Recirculation (EGR). Moreover, the internal EGR helps to achieve cost reduction, because catalyst jewelry weight is reduced. The Kappa is developed with Mechanical Lash Adjuster (MLA) tappet of the direct acting type, ❻, for reducing inertial mass of the valve system and saving costs. The MLA tappet is coated with Diamond Like Carbon (DLC) to improve fuel efficiency. DLC coating overcomes the disadvantage of increasing friction due to sliding contact between camshaft and tappet. In comparison with nitrification coating, the DLC coating gets 0.3 % better fuel economy by reducing valvetrain friction. The friction of the DLC-coated tappet is improved relatively better at low-engine speed than at high-engine speed. For improving fuel economy by reducing valvetrain inertial mass, Kappa uses a beehive valve spring. Similar to the shape of a beehive, the top diameter of the beehive valve spring is designed to be smaller than the bottom diameter. This lowers the weight of the retainer and valve spring and reduces the inertial mass of the valvetrain. Valvetrain friction is lowered by 10 % at whole engine speeds compared to a conventional valve spring. To reduce inertial mass, the MLA tappet minimizes wall thickness. It is 20 % lighter than other replacements, creating the smallest valve spring load and reducing friction.

INTAKE AND EXHAUST MANIFOLD

The three-cylinder engine is alternatively equipped with an intake manifold of constant length and a variable counterpart in order to achieve two power variants. In both cases the plenum is made of plastic to reduce weight and costs. To ensure high engine torque at middle speeds, the static tube corresponds to the long position of the switchable runner. The manifold length was verified by simulation and experiment and specified to 451 mm. The shape of the surge tank is changed to a



❺ Combustion chamber shape and layout of cylinder head



❻ Friction-optimized valvetrain

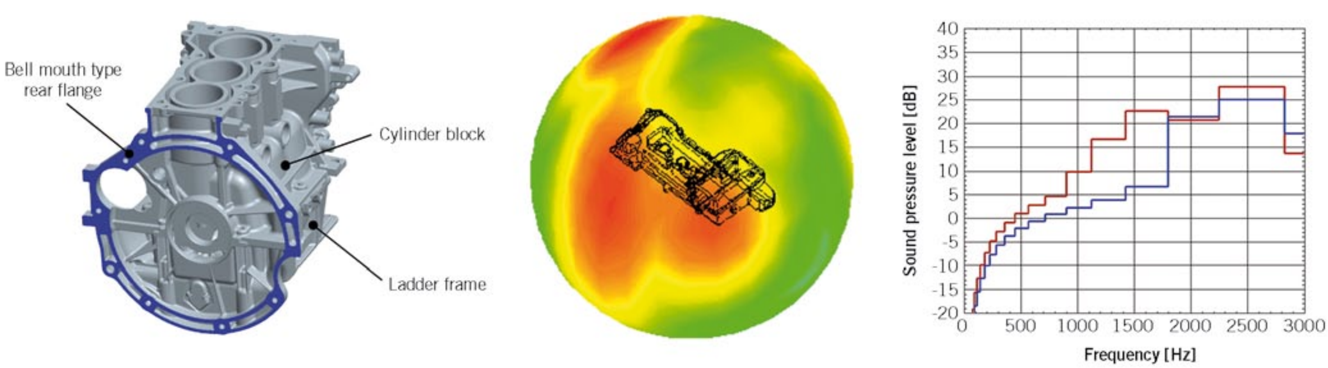
curved structure from the typical straight variety, which improves torque and maximum power by 1.0 Nm and 1.5 kW, respectively. The exhaust manifold is made of cast iron, thereby reducing cost by 30 % compared to a stainless steel exhaust manifold. The increased content of silicium enables the Kappa to resist oxidation under high-temperature conditions and to improve the catalyst durability. The new engine fulfils the latest Euro 5 standard.

OPERATION STRATEGY

All derivatives of the new three-cylinder engine are available in combination with an engine start-stop system which lowers fuel consumption by approximately 3 %. The decision to implement an engine start-stop system was taken after evaluating a number of single parameters, such as the clutch pedal position, the shift lever, vehicle speed, level of battery charging, the outside temperature and electrical consumption. In the algorithm, safety-relevant aspects get highest priority. Vehicles with a start-stop system have a more efficient starter as well as a battery with higher capacity. An Alternator Management System (AMS) controlling the alternator based on driving conditions is also used and increases fuel economy by about 1.5 %.

OPTIMIZATION OF ENGINE AND VEHICLE ACOUSTICS

For reducing noise when the engine is at idle, a ramp profile of the camshaft is optimized to eliminate vibration from valve action. The shape and volume of the delivery pipe are changed to decrease ticking noise of an injector, thereby minimizing the high-frequency noise component. In order to reduce radiated noise in Wide Open Throttle (WOT), the engine

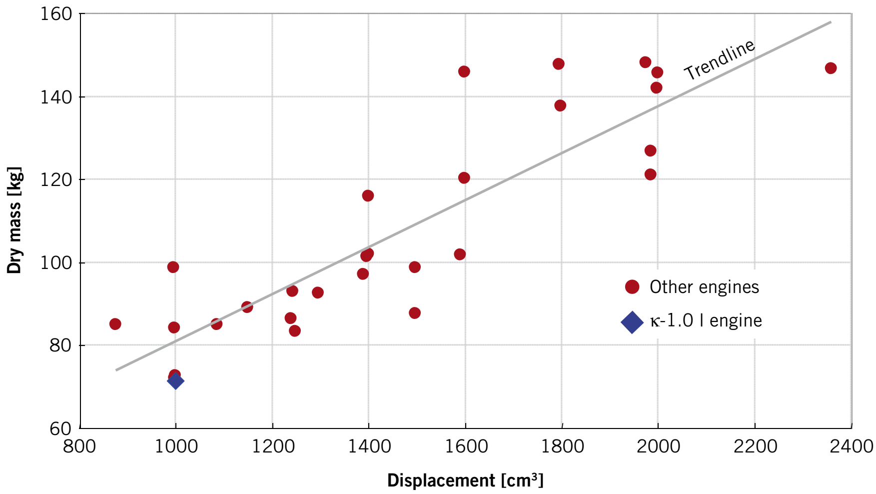


NVH-optimized crankcase with vigorous weight reduction

Radiation noise analysis of head cover

Noise optimization of chain cover

❼ Improvement examples by NVH analysis



❽ Dry mass of new κ 1.0 l engine in comparison to competitor engines

structure is analyzed and modified by using extensive CAE. Also, to improve engine NVH, a high-strength aluminium engine block and ladder frame are used. The circular matching structure allows the powertrain to be stiffened. Additionally, compact and strong accessory packaging is applied by directly mounting both the alternator and air conditioning compressor on engine block. To reduce radiated noise, the vibration path from piston to ladder frame is optimized and radiation from radiation surfaces such as head cover, chain cover and in/exhaust is reduced.

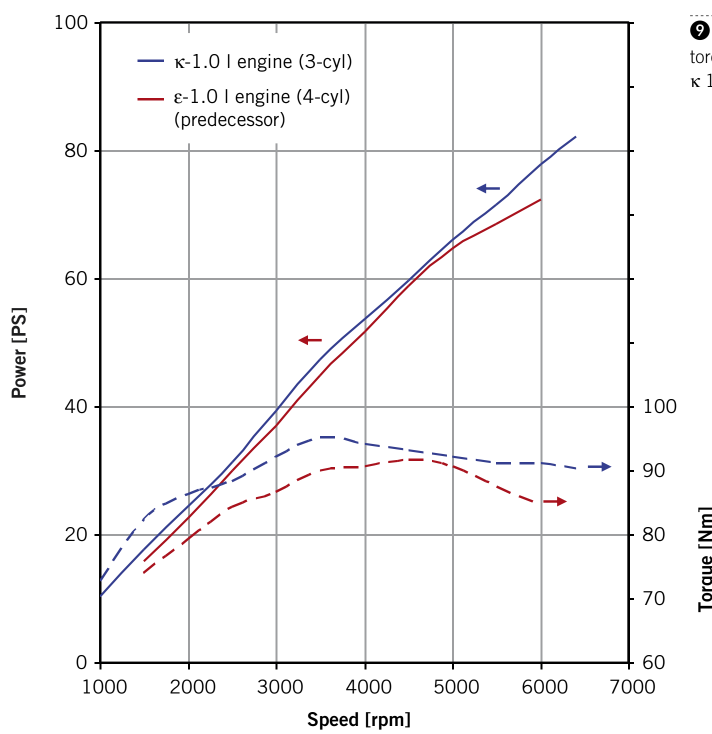
❼ shows the analytical results of reduction of vibration and radiated noise from a chain cover and a head cover by using CAE. To reduce rumble noise from the engine partial load operation conditions, ECU data, such as spark timing, are optimally matched. To decrease both whine and ticking noise of the chain drive a Pressure Regulation Valve (PRV) is applied to the chain tensioner. Also, cooling fan noise of the alternator at middle- and high-speed acceleration was reduced by applying a dual fan configuration. Vibration level in the vehicle interior is reduced by using a stiffer dash panel and a dense isolation pad.

BI-FUEL VARIANT FOR DRIVING WITH GASOLINE AND LPG

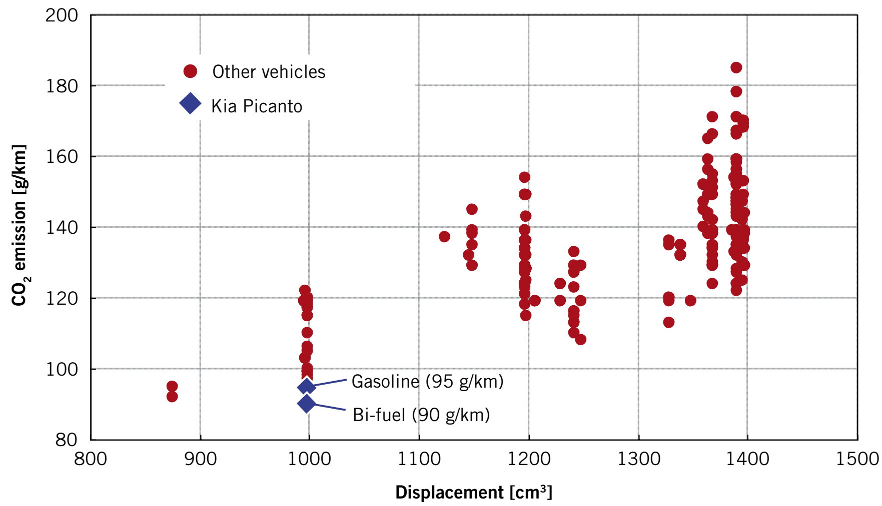
With tightened CO_2 regulations and oil price fluctuation, the need for developing an LPG engine is growing. However, because of the shortage of LPG infrastructure, demands on the development of Bi-Fuel engine – which consumes both gasoline and LPG fuel – are increasing. To meet these needs, Hyundai-Kia has developed the 1.0 l LPI Bi-Fuel version of the Kappa. Volumetric efficiency of the Kappa 1.0 l Bi-Fuel engine is improved by applying a Liquid Petroleum Injection (LPI) system. This injects LPG into each cylinder head port's entrance and controls the rate of fuel flow accurately. Therefore, CO_2 is reduced by 5 % while power is improved as much as in the gasoline variant. The Kappa LPI Bi-Fuel engine is equipped with both gasoline and LPG injector. And because of poor conditions in the combustion chamber caused by the dry characteristic of LPG, superior valve seats and valves in properties of abrasion, corrosion and heat conductivity are developed. Also, the piston top ring is PVD (Physical Vapour Deposition) coated to improve durability.

RESULTS

With the application of the latest technologies, such as Dual CVVT and the switchable intake manifold (VIS), the new Kappa 1.0 l engine achieves the best-in-class performance. The same technologies in combination with a carefully detailed optimization – particularly in the field of the engine mechanics – allow partial-load fuel consumption to represent a new optimum within the competitor engines ($\lambda = 1$ and Non-EGR) with a value of only 375 g/kWh at 2000/min and 2 bar. By using various technologies to decrease noise, the Kappa improves NVH quality about 2 to 3 dB over competitive engine at whole engine running zones. To reduce weight, the Kappa uses an aluminium



❾ Performance and torque curve of the new κ 1.0 l engine



❿ CO_2 emission of new Kia Picanto in the field of competitors

cylinder block, plastic intake manifold and other technologies. Through strain and stress analysis and NVH development, the shape of rib is optimized and the thickness of the wall becomes thinner. As a result, the Kappa weighs only 71.4 kg, making it the lightest 1.0 l engine in comparison to competitor engines, ❽.

SUMMARY AND OUTLOOK

The interdisciplinary efforts in the course of the development of the new Kappa 1.0 l engine led to an aggregate with high power and efficiency. The derivate with switchable intake manifold delivers 60 kW/82 PS and achieves a maximum torque of 94 Nm, ❾. The specific advantages of the three-cylinder concept, the application of selected technologies – such as start-stop system, but also detailed optimizations of all components – contribute to an efficient vehicle engine. High requirements for comfort were fulfilled by consistent treatment of the concept-specific challenges. CO_2 emissions of 95 g/km for the new Kia Picanto with a gasoline engine and 90 g/km for the variant with Bi-Fuel engine identify a new benchmark in the 1.0 l class, ❿. As the further variant, the production of an ethanol-compatible engine (FFV) will start within 2011; a turbocharged version of the 1.0 l engine is under development and will mark a further, consistent step toward sustainable mobility in near future.

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