GASOLINE ENGINES

1 Introduction

On February 24, 2022, Russia invaded Ukraine, prompting a jump in crude oil prices, which had already been on the upswing from the second half of 2021.

At the same time, in response to the 2022 United Nations Climate Change Conference (COP 27), a number of countries and regions around the world announced bans on new internal combustion engine (ICE) vehicle sales and measures to encourage sales of battery electric (BEVs) and plug-in hybrid electric vehicles (PHEVs). On August 8, the U.S., government enacted the Inflation Reduction Act that contains provisions aiming to popularize zero emission vehicles (ZEVs) such as BEVs, PHEVs, and fuel cell electric vehicles (FCEVs). Then, on August 25 and September 29, California and New York states announced plans for ZEVs to make up 100% of new vehicle sales by 2035. On October 27, the European Parliament and the Council of the European Union (EU) agreed provisionally to, in practice, ban sales of new gasoline-powered vehicles by 2035. This ban was then approved by the European Parliament on February 14, 2023. China define BEVs, PHEVs, FCEVs, and the like as new electric vehicles, and has worked to popularize these models since 2012. In 2022, annual sales of new electric vehicles increased by 79.3% to 5.249 million units. Similarly, Japan defines BEVs, PHEVs, FCEVs, and clean diesel vehicles (CDVs) as clean energy vehicles (CEVs). Subsidies designed to popularize these vehicles helped increase BEV sales in 2022 by 2.7 times compared to 2021. As these results show, active efforts are under way to expand the popularity of BEVs.

Despite this background, sixteen new gasoline engines were launched in Japan, the U.S., and Europe in 2022. Research and development is continuing into improving thermal efficiency, with substantial progress being made, particularly in China.

This article introduces the latest information for gasoline engines launched in 2022.

2 Japan

2. 1. Overview

Sales of new vehicles in Japan in 2022 reached 4.2 million units for registered and mini-vehicles combined. This was a drop of 5.6% compared to 2021 and the fourth successive year-on-year decline. This decrease was mainly due to ongoing disruption in the semiconductor supply chain, which caused manufacturers to temporarily halt production at plants, resulting in a drop in production over the whole year. Sales of mini-vehicles alone reached 1.63 million units, 0.9% lower than in 2021. Again, this was the fourth successive year-on-year decline. At the same time, the electrification of vehicle sales is progressing, with HEVs making up 49% of passenger vehicles sales, PHEVs 1.7%, and BEVs 1.4%. All three categories of vehicles recorded increases in 2022.

Highly efficient gasoline engines for HEVs accounted for half of the newly developed gasoline engines in 2022, with pure gasoline engines limited to models aimed at customers with a preference for sporty models.

2. 2. Trends of Each Manufacturer

Table 1 lists the new gasoline engines launched by

Fig. 1 Toyota G16E-GTS

Table 1 Main New Engines in Japan

Manufacturer	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Intake system	Fuel injection system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles equipped with this engine	Characteristics
Toyota	G16 E-GTS	L3	⌀87.5 × 89.7	1.618	10.5	DOHC 4-valve	TC	DI+PFI	224/6,500	370/3,000 –5,550	GRCorolla	Strengthened exhaust camshaft bearings, valve-driven triple exhaust pipe, aluminum oil cooler with improved cooling performance, higher discharge fuel pump, strengthened pistons
Nissan	HR14 DDe	L3	⌀78.0 × 100	1.434	13.0	DOHC 4-valve	NA	DI	72 /5,600	123/5,600	Serena e-Power	Multi-link variable compression ratio mechanism, LP-EGR, electric intake VVT (with mid-position exhaust lock mechanism), M10 spark plugs, high energy 110 mJ ignition, multifunction valve cooling control, mirror bore coating, ball bearing for #1 cam bearing, integrated exhaust manifold and cylinder head, variable capacity oil pump, heat-resistant turbocharger up to 1,050℃
	KR15 DDT	L3	⌀84.0 × 90.1 –88.9	1.497 –1.477	8.0 – 14.0	DOHC 4-valve	TC	DI	106/4,400 –5,000	250/2,400 –4,000	X-Trail, Rogue	Variable compression ratio, LP-EGR, electric VVT (with mid-position exhaust lock mechanism), 110 mJ M10 spark plugs, mirror bore coating, variable capacity oil pump, heat-resistant turbocharger up to 1,050℃
Mazda	PY-VPH	L4	⌀89.0 × 100	2.488	13.0	DOHC 4-valve	NA	DI	138/6,000	250/4,000	CX-60 PHEV	Plug-in hybrid system, direct in-cylinder injection, VVT mechanism, Miller cycle, battery charge control, start-stop system
	PE-VPS	L4	⌀83.5 × 91.2	1.997	13.0	DOHC 4-valve	NA	DI	115/6,000	199/4,000	Mazda3, CX-30	Mild hybrid system
Honda	LFC	L4	⌀81.0 × 96.7	1.993	13.9	DOHC 4-valve	NA	DI	104/6,000	182/4,500	Civic e:HEV	Maximum fuel pressure: 35 MPa, electric intake VVT mechanism, hydraulic exhaust VVT mechanism, auxiliary balancer
	K20 C	L4	⌀86.0 × 85.9	1.995	9.8	DOHC 4-valve	TC	DI	243/6,500	420/2,600 –4,000	Civic Type R	Enhanced turbocharger (lower bearing friction loss, smaller compressor blades, more compact turbine scroll)

manufacturers in 2022, which are summarized below.

(1) Toyota

The 1.6-liter inline 3-cylinder G16E-GTS turbocharged engine (Fig. 1) has the same model designation as the engine mounted on the GR Yaris that debuted in 2020. Maximum power was increased from 200 to 224 kW at 6,500 rpm to match the weight of the GR Corolla, which is 200 kg heavier than the Yaris. The engine is connected to three exhaust pipes to reduce exhaust gas pressure by opening a valve at high engine speeds. The intake port shape and exhaust valve diameter were also revised. To match the increased power, the exhaust camshaft bearing was strengthened. The pistons were also strengthened by adopting Niresist steel in the top ring grooves and carrying out shot blasting. Also in response to the higher power, the discharge pressure of the high-pressure fuel pump and the cooling efficiency of the aluminum oil cooler were both raised. In the same way as the engine mounted on the GR Yaris, innovative production techniques were also adopted to accommodate the weight of the pistons and connecting rod. The engine is assembled by highly skilled workers at the Shimoyama Plant.

Fig. 2 Nissan HR14DDe

(2) Nissan

The 1.4-liter inline 3-cylinder naturally aspirated HR14DDe engine (Fig. 2) was designed specifically to act as a generator. It is mounted on the Serena paired with the second-generation e-Power system. This engine has the same bore diameter as the HR12DE that was paired with the e-Power system in the previous generation Serena, but a longer stroke (increased from 83.6 to 100 mm), increasing the displacement to 1,434 cc. This long stroke engine has a bore-stroke ratio of 1.28 and a compression ratio of 13.0 (up from 12.0 in the previous generation). In addition to the mirror bore coating and dual injectors adopted on the HR12DE, the HR14DDe also features a variable valve timing (VVT) mechanism and larger crankshaft main journal diameter, increasing the power of the engine to 72 kW. In the partial load region, the VVT mechanism realizes a high expansion ratio cycle that boosts thermal efficiency. The engine is also equipped with a variable capacity oil pump to lower friction loss and generates lower noise due to the adoption of a balancer on a separate shaft to the gear drive and a flexible flywheel. Since the engine is designed specifically as a generator, the cell motor bracket was eliminated, helping to raise the transaxle tightening stiffness. These noise and vibration (NV) measures help to reduce adverse driver reaction when accelerator pedal operation seems to be out of sync with the engine speed, and also helps to raise fuel efficiency by enabling the engine to operate at fixed operation points.

The 1.5-liter inline 3-cylinder turbocharged KR15DDT engine (Fig. 3) features a multi-link variable compression ratio mechanism and was installed in combination with a continuously variable transmission (CVT) on the X-Trail and other models in China. The Japanese version of this engine is paired with the second-generation e-Power system. Since this engine is paired with a generator, its maximum power is only 106 kW combined with 150 kW outside Japan. However, this is offset by the adoption of a low-pressure exhaust gas recirculation (LP-EGR) system incorporating an admission valve in the intake path. This expands the $\lambda = 1$ region, raises the fuel pressure to 35 MPa, and enables the engine to operate by direct injection alone. In addition, the e-Pedal Step system that incorporates a cooperative brake function shares the hydraulic brakes during motoring when power is being consumed. This increases the maximum deceleration of the regenerative brakes to 0.20 G and helps to raise fuel


Fig. 3 Nissan KR15DDT

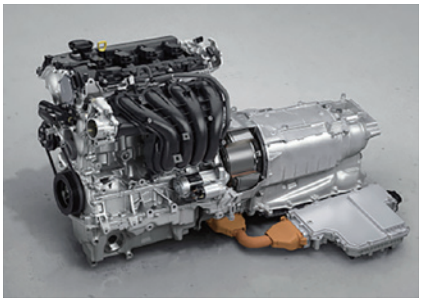
Fig. 4 Mazda PY-VPH


Fig. 5 Mazda PE-VPS

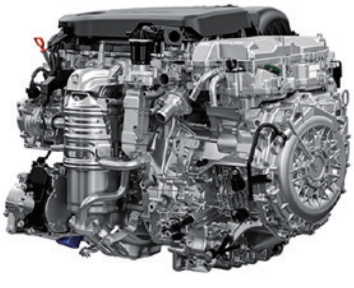
Fig. 6 Honda LFC

Table 2 Main New Engines in the U.S.

Manufacturer	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Intake system	Fuel injection system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles equipped with this engine	Characteristics
Ford	99 A	V8	ø107 × 93	6.751	10.8	OHV 2 -valve rocker arm	NA	PFI	302 /5,000	603 /4,000	F-Series Super Duty	VVT mechanism
GM (Chevrolet)	L8 T(Not released)	V8	ø103.25 × 98	6.564	10.8	OHV 2 -valve rocker arm	NA	DI	299 /5,200	629 /4,001	Silverado HD	In-cylinder direct injection
	LT6	V8	ø104.25 × 80	5.463	12.5	DHHC 4 -valve	NA	DI	500 /8,400	623 /6,300	Corvette Z06	Flat crankshaft, titanium intake valves, cast aluminum pistons, dry sump oil system, diamond-like carbon coating (on piston rings and cam follower)

Fig. 7 Honda K20C

Fig. 8 Ford 99A

efficiency.

(3) Mazda

The 2.5-liter direct injection PY-VPH gasoline engine (Fig. 4) paired with Mazda's first plug-in hybrid system (the e-SKYACTIV PHEV system) adopts a form of stratified charge combustion that was reconsidered from the ground up to enhance the exhaust gas performance during catalyst warm up. As a result, it halves the total hydrocarbon emissions of the previous system up to an engine torque of 150 Nm.

In addition, the PE-VPS (Fig. 5) is called e-SKYACTIV-G 2.0 since it pairs the existing SKYACTIV-G 2.0 engine with a mild hybrid system.

(4) Honda

The LFC (Fig. 6) is a 2.0-liter inline 4-cylinder naturally aspirated engine mounted on the Civic e-HEV. The LFC is part of the same engine family as the LFA and LFB models already mounted on Honda's hybrid vehicles, and is primarily characterized by its direct injection system. It also features enhanced low-emission technologies in response to upcoming new real driving emissions (RDE) regulations, and incorporates a range of measures to accommodate higher power. These low-emission technologies include combining high fuel pressure direct injectors with a multi-injection strategy, a catalyst that activates at low temperatures, and a higher upper limit stoichiometric catalyst temperature. Measures for the higher power produced by the engine include a two-piece water jacket built-into the cylinder head, exhaust ports with a larger surface area, larger diameter exhaust valves, the adoption of a hydraulic VVT mechanism on the exhaust side, and an electric water pump with a higher flow rate. These are complemented by measures to raise fuel efficiency, such as combustion chambers with a low surface/volume (S/V) ratio, a long stroke design (bore-stroke ratio: 1.2), port geometry that generates high tumble, and piston top surface geometry that maintains the generated tumble. NV measures include adopting an electric VVT mechanism, increasing the stiffness of the crankshaft, and providing an auxiliary balancer. The cost of the engine was reduced by omitting the V-TEC system and by adopting a plastic intake manifold, a catalyst with a lower precious metal content, and a compact water

Table 3 Main New Engines in Europe

Manufacturer	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Intake system	Fuel injection system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles equipped with this engine	Characteristics
VW	DLA	L3	ø74.5 × 76.4	0.999	11.4	DOHC 4 -valve	TC	DI	70 /5,000 – 5,500	175/1,600– 3,500	Polo	VVT mechanism, DSG (DCT), Miller cycle combustion, variable turbocharger geometry
	DNF	L4	ø82.5 × 92.8	1.984	9.3	DOHC 4 -valve	TC	DI	235/5,350– 6,500	420/2,100– 5,350	Golf R Tiguan R	High-pressure injection (350 bar), VVT mechanism, DSG (DCT)
Audi	CXY	V8	ø86.0 × 86.0	3.996	11.0	DOHC 4 -valve	TC	DI	338 /5,500	660/1,850– 4,500	A8 60 TFSI Quattro	Electronic throttle, VVT mechanism, mild hybrid system
BMW	S68	V8	ø89.0 × 88.3	4.395	10.5	DOHC 4 -valve	TC	DI	390/5,500– 6,000	750/1,800– 4,600	X7 M60 i xDrive	Twin turbochargers, high-pressure injection (350 bar), cross-bank exhaust manifold, double-VANOS, Valvetronic, mild hybrid system
	B58B30 M2	L6	ø82.0 × 94.6	2.998	11.0	DOHC 4 -valve	TC	DI+PFI	276/5,200– 6,250	540/1,850– 5,000	740 i	Dual injection system, VANOS, Valvetronic, active ignition coils, mild hybrid system
Stellantis	Hurricane Twin-Turbo I-6 -SO	L6	ø84.0 × 90.0	2.993	10.4	DOHC 4 -valve	TC	DI	309 /5,200	635 /3,500	Wagoneer	High-pressure injection (350 bar), charged air cooler, dual water-exhaust gas recirculation, PTWA sprayed cylinder coating, cooled EGR (SO only), low-inertia turbocharger
	Hurricane Twin-Turbo I-6 -HO	L6	ø84.0 × 90.0	2.993	9.5	DOHC 4 -valve	TC	DI	375 /5,700	678 /3,500	Grand Wagoneer	

pump.

The Civic Type R that debuted in 2022 is equipped with the K20C engine (Fig. 7) featuring a redesigned turbocharger that boosts maximum power to 243 kW and maximum torque to 420 Nm. This engine also includes a VVT and lift mechanism on the exhaust side and continuous VVT control mechanisms on both the intake and exhaust sides. These measures improve turbocharger response and wide-open throttle power at low engine speeds, while also helping to improve fuel efficiency.

3 The U.S.

3. 1. Overview

Sales of new vehicles in 2022 reached 14,230,324 units, 7.6% lower than in 2021. Of these, passenger vehicle sales dropped by 14.7% to 2,858,575 units and light truck sales also dropped by 6.0% to 10,895,764.

3. 2. Trends of Each Manufacturer

Table 2 shows the major new engines launched in the U.S. market in 2022, which are summarized below.

(1) Ford

Ford developed a new 6.8-liter V8 gasoline engine called the 99A (Fig. 8), which it plans to mount on the F-Series Super Duty. This engine combines a cast iron cylinder block with an aluminum alloy cylinder head. It also features a VVT mechanism and its size was reduced by installing the cam inside the cylinder block.

Fig. 9 GM LT6

(2) GM

The L8T is a 6.6-liter V8 gasoline engine mounted on the Chevrolet Silverado that generates peak torque of 629 Nm at an engine speed 200 rpm lower than the previous 6.0-liter V8 HD engine. This engine adopts direct injection technology that enables precise fuel control and a high compression ratio, helping to realize flatter torque characteristics and maximum power of 299 kW.

In addition, the LT6 is a 5.5-liter V8 engine (Fig. 9) mounted on the Chevrolet Corvette Z06 and features a flat-planed crankshaft, titanium cast connecting rod and intake valves, and low-profile cast pistons. These mea-

Fig. 10 VW DLA

sures reduce the moment of inertia, and enable rapid acceleration and deceleration as well as higher engine speeds.

4 Europe

4. 1. Overview

In 2022, sales of new passenger vehicles in the 26 countries of the European Union (EU) (excluding Malta) reached 9.25 million units. Sales were deeply affected by supply chain disruption in the first half of the year and fell by 4.6% to the lowest level since the 1930s. Vehicle electrification is advancing in Europe, with HEVs accounting for a market share of 22.6%, PHEVs for 9.4%, and BEVs for 12.1%. All three categories of vehicles recorded increases in 2022.

4. 2. Trends of Each Manufacturer

Table 3 shows the major new engines launched in the European market in 2022, which are summarized below.

(1) Volkswagen

The DLA (Fig. 10) is a 1.0-liter inline 3-cylinder turbocharged engine mounted on the Polo. In addition to achieving higher engine efficiency by adopting a Miller cycle combustion process and a variable turbocharger geometry mechanism, emissions performance was also enhanced by installing a PM filter in the engine.

The DNF is a 2.0-liter inline 4-cylinder turbocharged engine mounted on the Golf R and Tiguan R. Compared to the previous generation, maximum power was increased by 7.35 kW to 235 kW and maximum torque by 20 Nm to 420 Nm. This torque is generated over a wide range of engine speeds from 2,100 to 5,350 rpm.

(2) Audi

The CXY is a 4.0-liter V8 turbocharged engine that was paired with a mild hybrid system and mounted on the new A8 that debuted in 2022. It uses twin turbochargers to produce power of 338 kW and realize flat torque generation of 660 Nm between 1,850 and 4,500 rpm.

Fig. 11 BMW S68

Fig. 12 BMW B58B30M2

(3) BMW

The S68 is a 4-4-liter V8 turbocharged engine (Fig. 11) mounted on the X7 M60i xDrive. It was developed as the successor to the high-performance M-series S63 engine. This engine maintains the same bore × stroke dimensions as the S63, but the compression ratio was increased from 10.0 to 10.5. It features a cross-bank exhaust manifold and distributes the exhaust gas uniformly between twin turbochargers to realize rapid response. In addition, the engine is paired with a 48 V mild hybrid system, which improves efficiency by enabling operation at constant engine speeds and in constant load ranges.

The B58B30M2 (Fig. 12) is a 3.0-liter inline 6-cylinder turbocharged engine mounted on the 740i. It features minor updates to the B58 B-type modular engine 6-cylinder model. This engine is also paired with a 48 V mild hybrid system and adopts an electric variable camshaft control system (VANOS) instead of the original hybrid system. Other features include a dual injection system that reduces PM and CO_2 by enabling partial port injection in

Fig. 13 Stellantis Hurricane Twin-Turbo I-6-SO

addition to conventional direct injection. The VVL system (Valvetronic on the intake side and rocker arm activation on the exhaust side) allows cylinder deactivation. These measures lower engine friction loss by one-third and enable greater energy regeneration.

(4) Stellantis

In its Dare Forward 2030 strategy plan, Stellantis announced that it was targeting a 50% reduction in CO_2 emissions by 2030 and net carbon zero by 2038. Reflecting these goals, the 3.0-liter inline 6-cylinder Hurricane Twin-Turbo engine (Fig. 13) is designed to accommodate future electrification. This engine includes a standard-specification version (Standard Output: SO) and a high-power version (High Output: HO). The SO is mounted on the Wagoneer and the HO is mounted on the Grand Wagoneer. The SO has a peak boost pressure of 0.15 MPa, a maximum power of 309 kW at 5,200 rpm, and a maximum torque of 635 Nm at 3,500 rpm. It is also equipped with a single inlet charge cooler with its own cooling circuit. The SO engine also adopts cooled EGR to reduce pumping loss and improve fuel efficiency. The PO has a higher peak boost pressure of 0.18 MPa, a maximum power of 375 kW at 5,700 rpm, a maximum torque of 678 Nm at 3,500 rpm, and a dual inlet charge cooler. These two engines are equipped with two low inertia turbochargers each connected to three cylinders to enable rapid response to throttle inputs. The cylinder bores have a thin plasma transfer wire arc (PTWA) sprayed cylinder coating for lower friction. A high flow rate ball valve thermostat is adopted to minimize cooling system throttling and reduce mechanical loss. A variable capacity oil pump is used to adjust pump output in accordance with the engine state. This pump reduces mechanical loss and helps to save fuel.

5 China

5. 1. Overview

Sales of new vehicles in 2022 rose by 2.1% from 2021 to 26.864 million units. As described in the following section, manufacturers are engaged in fierce competition to raise the thermal efficiency of gasoline engines for HEVs and PHEVs.

5. 2. Trends of Each Manufacturer

The sub-sections below describe an overview of the gasoline engines introduced in 2022. However, it was decided to omit a table of specifications for engines manufactured in China since many aspects of these specifications are unclear.

(1) Dongfeng Motor

Although outside the nominal scope of this article, in February 2023, Dongfeng announced that its new Mach 1.5T engine achieves a maximum thermal efficiency of 45.18%. This is the first gasoline engine for HEVs manufactured by the Chinese automotive industry to achieve a thermal efficiency above 45%.

(2) Geely Automobile

On February 24, 2023, Geely announced that the NordThor 8848, which it plans to install on its Galaxy series of models, achieved a maximum thermal efficiency of 44.26%.

(3) BYD

The 1.5-liter engine for PHEVs mounted on the Qin Plus DM-i is a highly efficient inline 4-cylinder engine that produces maximum power of 81 kW and maximum torque of 135 Nm, and achieves a thermal efficiency of 43%.

6 Trends in Research and Development

6. 1. Government-Industry-Academia Collaboration

(1) Research Association of Automotive Internal Combustion Engines (AICE)

AICE is continuing research as part of a government-industry-academia partnership defining the following four steps as technical scenarios: (1) raising average thermal efficiency, (2) raising engine thermal efficiency to increase maximum thermal efficiency, (3) AI controls, weight reduction, and the like, and (4) aiming to achieve zero CO_2 emissions using carbon-mitigation technologies such as carbon-neutral fuels.

(2) Zero Emission Mobility Power Source Research Consortium

This consortium was founded in 2020 with the aim of achieving zero emissions for mobility through research on power sources. It promotes industry-academia collaboration by providing a forum for academic members to engage in discussions with corporate members.

(3) Japan Automotive Model-Based Engineering Center (JAMBE)

This organization was founded in 2021 with the aim of achieving a state-of-the-art development community in a mobility society in which totally optimized and sophisticated manufacturing is implemented highly efficiently without redo. It is currently working to enable digital modeling from the initial stages of development.

(4) Research Association of Biomass Innovation for Next Generation Automobile Fuels

This association was established with the objective of researching efficient production technologies for automotive bioethanol fuels to help achieve a carbon-neutral society.

6. 2. Research Papers

This section briefly describes the 2022 JSAE Awards-winning papers that are closely related to this article.

(1) A Study of Spark Discharge Characteristic for Improving the Thermal Efficiency of SI Engine (First and Second Reports)

Matsubara et al. applied an ignition phenomena index proposed by a Cross-Ministerial Strategic Innovation Promotion Program (SIP) project covering innovative combustion technologies to an actual engine, and proposed the discharge Péclet number as a new ignition index. This research identified a close correlation between this index and the average value of a combustion index called the SA-CA 2% time, which is defined as the time from the start of discharge until 2% of the total heating value is generated.

This research then focused on the effects of the discharge length on ignition and used an empirical formula to provisionally calculate the time history of the spark channels in each cycle. After verifying the effects with respect to the average cycle discharge length index and the SA-CA 2% time in each cycle, it was concluded that expanding the total discharge length (i.e., the time integration of the discharge length history) regardless of the discharge time and maximum discharge length is important for improving ignitability. In addition, studies of the effects of discharge length with respect to cycle variations found that the SA-CA 2% time tends to shorten as the total discharge length increases and that, if variations in the total discharge length can be suppressed, it may be possible to improve the lean limit.

(2) Method of Estimating Knocking Noise and In-Cylinder Pressure from Radiant Engine Noise by Deep Learning

Kasahara et al. developed a technique that uses a deep neural network (DNN) capable of estimating the in-cylinder pressure at which knocking occurs and quantitatively evaluating knocking intensity based on radiant engine noise. Compared to conventional auditory evaluations of knocking intensity, the quantitative evaluation aspect of the developed technique should also help to increase the efficiency of ignition timing calibration work. First, this research carried out learning from paired data consisting of radiant engine noise and the in-cylinder pressure at which knocking occurs. A DNN was then built that isolates knocking noises from the radiant engine noise. Next, it was verified that knocking noises could be isolated from radiant engine noise at 1,000, 3,000, and 5,000 rpm, and an index was proposed that can quantitatively evaluate the intensity of knocking.

(3) Clarification of Oil Transport Mechanism by Measurement of Oil Control Ring Behavior

Sakuma et al. focused on oil loss via the piston ring to identify the mechanism of oil consumption, developed technology to measure the behavior and oil film of the oil ring during engine operation, and proposed a method for reducing oil consumption. This research visualized the oil behavior in each stroke from intake to exhaust and evaluated differences in behavior based on various external side rail geometries. The results found that the sealing performance of the upper surface of the oil ring affects the oil behavior in each stroke. In addition, measurement results of the oil distributions in the circumferential direction of the 3rd land identified asymmetric geometry around the oil ring groove that resulted in large amounts of oil flowing from the groove to the 3rd land. Since the quantity of oil at the 3rd land was found to have a close correlation with oil consumption, it may be possible to reduce oil consumption by narrowing the gap at the oil ring groove.

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