GASOLINE ENGINES

1 Introduction

In the wake of the October 2020 declaration of carbon neutrality by 2050 by the Japanese government, the Ministry of Economy, Trade and Industry (METI) announced a green growth strategy the following December. That strategy aims to have electric vehicles constitute 100% of new passenger vehicles sold by the mid-2030s at the latest. Similarly, the Tokyo Metropolitan Government announced its own policy of having electric vehicles make up 100% of new passenger vehicles sold by 2030. These announcements press automobile manufacturers to accelerate electrification.

The European Commission publicly proposed raising the CO_2 reduction target for 2030 in Europe from the original 40% compared to 1990 to at least 55%.CO2 As a result, increasing the 2030 new vehicles CO_2 reduction target of 37.5% compared to 2021, which was set in 2019, is also under consideration. A plan to deploy 30 million zero emission vehicles (BEVs and FCVs) by 2030 has also been announced.

In the U.S., the Obama administration had decided to regulate the corporate average fuel economy for 2025 to 46.7 miles per gallon (mpg) in 2012, but the Trump administration announced it would significantly relax that regulation to 40.4 mpg for 2026. However, President Biden reinstated the stricter standard, and also publicly committed to extensively promote electrification. In addition, the State of California announced that by 2035, all light vehicles sold would be ZEVs, and that the sale of gasoline and diesel vehicles would be banned.

This article introduces the main gasoline engine and new technologies developed and launched between January and December 2020, and presents the research and development trends for such engines.

2 Japan

2. 1. Overview

Sales of new vehicles in 2020 dropped by 11.5% compared to the previous year (2019), to 4.6 million vehicles. This was a second consecutive year of decrease, and the first time in four years that sales dropped below 5 million vehicles. The curbing of spending triggered uncertainty about the future as the COVID-19 pandemic spread was the main factor in that decrease. With the spread of COVID slowing down in and after October, sales recovered to a positive level compared to the same month in the previous year in reaction to that curbing. The number of registered vehicles dropped to 2.88 million vehicles, a third consecutive year of decrease, and falling below 3 million for the first time since the 2011 Great East Japan Earthquake nine years earlier. Sales of mini-vehicles fell for the second year in a row, leveling off at 1.72 million vehicles.

Compared to the previous year (2019), the number of new engines announced or launched decreased considerably, possibly as a result of industry-wide policies to intensify development in the fields of automated driving and electrification.

2. 2. Trends of Each Manufacturer

Table 1 lists the new gasoline engines launched or announced by manufacturers in Japan in 2020, which are summarized below.

(1) Toyota: The G16E-GTS 1.6-liter L3 turbocharged engine (Fig. 1) has been installed in the GR Yaris homologation model designed to participate in the World Rally Championship (WRC). The uncommon displacement of 1,618 cc stems from the WRC regulations (1,620 cc or less), and an inline 3-cylinder design was chosen for its lack of exhaust interference and ability to boost low-to-medium speed torque. The engine operating region in the WRC event was analyzed to set the bore and stroke ratio (ϕ87.5 × 89.7) that maximizes performance in the

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

Table 1 Main New Engines in Japan

Manu-facturers	Engine model	Cylinder arrange-ment	Bore × stroke (mm)	Displace-ment (L)	Compres-sion ratio (-)	Valve train	Intake system	Fuel supply system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main ve-hicles with this engine	Characteristics
Toyota	G16E-GTS	L3	φ87.5 × 89.7	1.618	10.5	DOHC 4-valve	TC	DI	200/6,500	370/3,000 to 4,600	GR Yaris	Shallow bottom water jacket, high-strength aluminum cylinder head, hollow assembly camshaft, bearing turbocharger using ceramic ball bearings
	M15A-FKS	L3	φ80.5 × 97.6	1.49	14.0	DOHC 4-valve	NA	DI	92 /6,500 to 6,600	153/4,800 to 5,200	Yaris	Shared: Exhaust manifold integrated cylinder head, laser clad valve seat, higher compression ratio, cooled EGR, electric water pump, electronically controlled thermostat, variable valve timing FKS: resin driven gear balancer shaft FXE: Ultra-low viscosity oil
	M15A-FXE	L3	φ80.5 × 97.6	1.49	14.0	DOHC 4-valve	NA	PFI	68/5,500	120/3,800 to 4,800	Yaris Hybrid	
Nissan	MR15 DDT (Not released)	L3	φ79.7 × 100.2	1.499	13.5	DOHC 4-valve	TC	DI	Undisclosed	Undisclosed	Qashqai	STARC, no-valve seat high-tumble intake port, long stroke, EIVC Miller cycle
Subaru	CB18	H4	φ80.6 × 88.0	1.795	10.4	DOHC 4-valve	TC	DI	130/5,200 to 5,600	300/1,600 to 3,600	Levorg	Ignition assisted lean burn, high tumble intake port, MCV, FSV, IEM, piston pattern coating, variable capacity oil pump
Suzuki	K12 D	L4	φ73.0 × 71.5	1.197	13.0	DOHC 4-valve	NA	PFI	107/2,800	61/6,000	Ignis (UK specifications)	High-tumble intake port, MCV, electric VVT, variable capacity oil pump, electronically-controlled piston cooling jet

Fig. 1 Toyota G16E-GTS

Fig. 2 Toyota M15A-FKS

normal rally range. The engine uses a shallow bottom water jacket in the aluminum die cast cylinder block, a high-strength aluminum cylinder head, and a hollow assembly camshaft that combine with the application of high-precision machining to the pistons and crankshaft to simultaneously thoroughly reduce weight and ensure sufficient strength. High responsiveness was obtained by reducing friction through the use of ceramic ball bearings for the bearing structure of the turbocharger. In conjunction with the aforementioned weight reduction and the square configuration provided by the S/B ratio of 1.03, this achieves high linear response in any scenario. Intake temperature was also reduced by spraying water mist on the intercooler intake air cooling component, enabling the engine to maintain its normal high output even when during extreme driving in high outside temperatures.

The M15A-FKS/FXE1.5-liter L3 naturally aspirated engines (Fig. 2) installed in the Yaris are part of the dynamic force engine series based on the Toyota New Global Architecture (TNGA) concept. The high tumble and compression ratio resulting from the straight intake port and long stroke design increase the maximum thermal efficiency, which reaches 41% in the FXE engine for hybrid vehicles. The total balance design that eschews the counterweight on the second cylinder reduces the weight of the crankshaft itself. At the same time, the shape of the crankshaft bearing oil groove was optimized, decreasing the amount of oil leakage from the bearings, while friction was reduced by lowering the discharge performance of the oil pump.

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

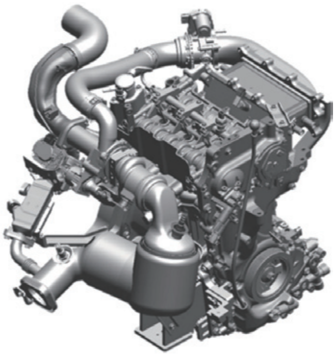

Fig. 3 Nissan MR15DDT

Fig. 4 Subaru CB18

(2) Nissan: The MR15DDT 1.5-liter L3 turbocharged engine (Fig. 3) was developed as a dedicated engine for the next-generation e-Power. Although various constraints and trade-offs previously had to be taken into account to address driving load changes due to the environment, the adoption of the new *Strong Tumble and Appropriately stretched Robust ignition Channel* (STARC) high-efficiency combustion concept in this engine dramatically enhances thermal efficiency by making it a fully fixed-point operating dedicated electricity generator. A strong tumble flow is formed through a no-valve seat technology relying on a cold spray that collides with the base material in a solid state at supersonic speeds without melting the material to form a film. Tumble is maintained until ignition, and the combination of a piston top surface with cavities suitable to regulating the tumble near the spark plugs and a combustion chamber that keeps the aspect ratio under control result in stable and highly dilute combustion.

The engine has a long stroke design with a bore and stroke of Φ 79.7 × 100.2 (S/B ratio: 1.26), with the injectors placed in the center of the combustion chamber. Featuring a high compression ratio of 13.5 despite being a turbocharged engine, it uses an early intake valve closing Miller cycle to reduce compression temperature, which combines with a high amount of EGR to mitigate knocking. Friction is reduced by the micro dimples applied to the crankpin and crankshaft main journal surface for oil retention and decreased bearing surface roughness purposes. Since this engine is exclusively used to generate electricity, there is no need to worry about transient response and misfiring. Therefore, the EGR amount is higher than in conventional engines, enabling improved thermal efficiency and achieving a maximum brake thermal efficiency of 43%.

(3) Subaru: The CB18 1.8-liter H4 turbocharged engine (Fig. 4) has been installed in the Levorg. This engine was developed with the objective of achieving both acceleration performance through turbocharging technology, and thermal efficiency through lean burn technology. Although lean burn is expected to greatly increase thermal efficiency, many obstacles must be overcome. The fuel spray was placed at the center of the combustion chamber and near the spark plugs, and the formation of a compact mixture was obtained by setting eight nozzle holes in the injector, to ensure stable ignition under lean air-fuel mixture conditions. Even as the combustion chamber as a whole is lean, stable ignition surpassing homogeneous lean burn is achieved by injecting a minute amount of fuel just before ignition to form a rich mixture around the spark plugs.

The drop in combustion speed due to lean burn was addressed by intensifying the air-fuel mixture turbulence. The intake port is laid on its side and has an elongated non-integrated portion that redirects air flow along the pent roof to suppress reverse tumble. Tumble flow is maintained until after the compression process by reducing asperities on the top surface of the pistons and creating a smooth main flow swirl. These technologies achieve a 52% stronger air-fuel mixture turbulence at the compression stroke top dead center, without relying on a tumble generator valve (TGV), than in the previous engine (FB16).

It is the first horizontally opposed engine in the world to use offset cylinders, reducing friction by up to 4% compared to engines with no offset. Applying pattern coating to the piston skirt suppresses the drag resistance of surplus oil and optimizes the thickness of the oil film. Friction was reduced by applying differently shaped patterns to achieve opposite actions on the thrust and coun-

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

Fig. 5 Suzuki K12D

terthrust sides. In addition, the use of an integrated exhaust manifold (IEM) covered by a water jacket for the exhaust ports, in conjunction with active cooling of the cylinder heads and exhaust side by the water jacket spacer, is effective at improving knocking resistance.

Thermo control valve-based heat management is complemented with control of flow distribution to the cylinder block and cylinder heads achieved through the use of block flow path valves. In the minimum advance for best torque (MBT) range, the temperature of the water is raised to initiate lean burn early as well as reduce cooling and friction loss, while in the knocking range, forcible cooling is used to lower the temperature of the water and boost output.

(4) Suzuki Motor Corporation: The K12D 1.2-liter L4 naturally aspirated engine (Fig. 5) has been installed in the UK-specifications Ignis. The intake port was made straight, and a jump edge was set at the valve entrance to form a homogeneous air-fuel mixture and achieve stable rapid combustion. The top surface of the piston was made into a two-stage ball that combines two types of concave shapes to intensify turbulence near the spark plugs while maintaining the strong flow generated in the port. At the same time, the valve diameter was broadened and valve lift raised to address the decrease in flow resulting from the intensified tumble. The coolant channels replace the previous mechanical thermostat with a coolant control valve that provides precise regulation of the coolant. Coolant flow is controlled to match the engine warm-up condition, and the warm-up time has been reduced by maintaining a high water temperature until the engine finishes warming up. This piston cooling jet uses an electronically-controlled valve that controls the opening and closing of the oil path to suppress knocking, and regulating the oil discharge according to the operating range mitigates coolant loss in ranges that do not require cooling, resulting in better fuel economy.

3 U.S.

3. 1. Overview

Sales of new vehicles in the U.S. in 2020 were 14.58 million vehicles, a 14.5% decrease over the previous year (2019). Due to the COVID-19 pandemic, this was the third largest decrease since the 1980s, following the major slowdowns caused by the global financial crisis in 2008 (18% drop) and 2009 (21.2% drop). The BEV/PHEV share of all vehicles was 2.0%, essentially the same level as in the previous year (2019), and manufacturer made progress on their initiatives for electrification.

3. 2. Trends of Each Manufacturer

Table 2 shows the major new engines launched in the U.S. market in 2020, which are summarized below.

(1) GM: The LIH 1.2-liter (Fig. 6) and L3T 1.35-liter (Fig. 7) L3 direct injection turbocharged engines share the same design despite having different individual bore and stroke ratios. They have been installed in the Buick Encore GX and the Chevrolet Trailblazer. The valve

Table 2 Main New Engines in the U.S.

Manufacturers	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio (–)	Valve train	Intake system	Fuel supply system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles with this engine	Characteristics
GM	LIH	L3	φ74.9 × 90.0	1.199	10.1	DOHC 4-valve	TC	DI	102/5,000	219/2,500	Chevrolet Trailblazer Buick Encore GX	Timing belt in oil
	L3 T	L3	φ79.0 × 90.1	1.341	10.1	DOHC 4-valve	TC	DI	115/5,500	236/1,600	Chevrolet Trailblazer Buick Encore GX	
	LT2	V8	φ103.25 × 92.0	6.162	11.5	OHV 2-valve	NA	DI	369/6,450	637/5,150	Chevrolet Corvette	AFM, dry sump oil system

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

Fig. 6 GM LIH

Fig. 7 GM L3T

drive system uses an orthodox rocker arm, and the spark plugs and injectors are placed at the center of the combustion chamber. The camshaft drive uses a belt running in oil, reducing both noise and friction compared to standard belt or timing chain drives. The cylinder block is made of cast aluminum, and suitable rib placement reduces liner deformation. The pistons are barrel-shaped, and the use of full-floating piston pins reduces friction. A cast aluminum frame has been added between the cylinder block and the oil pan and connecting it, as well as the crankshaft bearings rigidly reduces engine noise and vibration.

The LT2 (Fig. 8) is a 6.2-liter V8 naturally aspirated engine mounted on the Chevrolet Corvette. It features a control system called Active Fuel Management (AFM) that enhances both fuel economy performance and environmental friendliness by deactivating four of the cylinders at low engine loads. The engine is equipped with a dedicated dry sump oil system designed to avoid worsened engine performance even at lateral accelerations exceeding 1G, and even a full circuit run maintains the oil level in the engine and prevents a drop in performance. The intake and exhaust system design was also revised to improve output. The intake system uses intake runners with a total length of 210 mm and a throttle body with a bore of 87 mm. The valve lift was set to 14 mm.

Fig. 8 GM LT2

4 Europe

4. 1. Overview

Sales of new vehicles in Europe in 2020 were 11.96 million vehicles, a 24.3% decrease over the previous year (2019), falling below the previous year's results for the first time in two years due to the COVID-19 pandemic. Major European countries have announced bans on the sales, or entry in major cities, of gasoline and diesel vehicles. They have also started to offer substantial incentives (subsidies) for BEVs and PHEVs, which double as a measure to address the economic slowdown caused by the spread of COVID-19.

Since a certain number of new vehicles have to meet the regulatory value of 95 g/km for corporate average CO_2 emissions ahead of the introduction of the regulations in 2021, automobile manufacturers have focused their efforts on selling BEVs and PHEVs, leading to a rapid increase in sales of those vehicles in the latter half of 2020.

4. 2. Trends of Each Manufacturer

Table 3 shows the major new engines launched in the European market in 2020, which are summarized below.

(1) Jaguar Land Rover: Although the company had continued to use Ford engines since splitting from that company in 2008, it has been gradually releasing its newly developed Ingenium family in the market. The Ingenium family uses a modular design with a cylinder configuration ranging from three to cylinders, as well as longitudinal and transverse variations. The gasoline version was first introduced with the inline 4-cylinder 2.0-li-

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

Table 3 Main New Engines in Europe

Manufacturers	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio (–)	Valve train	Intake system	Fuel supply system	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main vehicles with this engine	Characteristics
Jaguar Land Rover	AJ150 : Ingenium 3		φ83.0 × 92.4	1.498	9.5	DOHC 4-valve	TC	DI	118/5,500	260/1,600 to 4,000	Jaguar E-Pace	
	AJ300 : Ingenium 6	L6	φ83.0 × 92.3	2.996	10.5	DOHC 4-valve	TC +SC	DI+PFI	400/5,500	550/2,000 to 5,000	Land Rover Defender	MultiAir Electric supercharger
Maserati	Nettuno	V6	φ88.0 × 82.0	3	11.0	DOHC 4-valve	TC	DI+PFI	463/7,500	730/3,000 to 5,000	Maserati MC20	Pre-chamber jet ignition (passive) Variable capacity oil pump Dry sump

Fig. 9 Jaguar Land Rover AJ150

Fig. 10 Jaguar Land Rover AJ300

ter AJ200 in 2015, which was followed by the release of the inline 3-cylinder 1.5-liter AJ150 (Fig. 9), and the inline 6-cylinder 3.0-liter AJ300 (Fig. 10) in 2019 and 2020.

The AJ300 has been installed in the Land Rover Defender. It combines an electric supercharger capable of reaching 65,000 rpm in 0.5 seconds and a twin-scroll turbocharger to boost power performance. The valvetrain consists of the Schaeffler MultiAir intake variable valve lift system as well as intake and exhaust variable valve timing, resulting in improved fuel economy performance.

Fig. 11 Maserati Nettuno

The AJ150 has been installed in the Jaguar E-Pace. It features the same direct injection and turbocharger system as the AJ300, but does not include the electric supercharger or the MultiAir system.

(2) Maserati: The 3.0-liter V6 turbocharged Nettuno engine (Fig. 11) installed in the mid-engine MC20 sports car. Its most notable characteristic is the use of the pre-chamber jet ignition system, a technology popular in modern F1 engines used in a mass market vehicle for the first time in the world. The passive pre-chamber does not have injectors, and relies on the flow in the cylinder to push the air-fuel mixture. Ignition is triggered by the spark plug in the pre-chamber and, and knocking is suppressed by the rapid combustion of the mixture in the main combustion chamber caused by the jet flame injected from the nozzle holes. In the low load range, another spark plug set at the edge of the main combustion chamber are used to trigger conventional combustion, and the two spark plugs are used to switch to the type of combustion appropriate to the operating range. The fuel supply system uses both direct injection (DI) and port fuel injection (PFI), with a maximum injection fuel pressure of 3.5 MPa for DI and 0.6 MPa for PFI. The engine also uses a twin turbocharger and dry sump lubri-

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

cation system.

5 Trends in Research and Development

5. 1. Government-Industry-Academia Collaboration

(1) Research Association of Automotive Internal Combustion Engines (AICE): The second phase of AICE activities began in April 2019. It aims to integrate power sources relying on an internal combustion engine with the connected, autonomous, shared, and electric (CASE) concept, and reduce the well-to-wheel CO_2 from such sources to the same level as electric vehicles in 2030 while targeting zero CO_2 emissions in 2050. Its initiatives focus on themes such as improving thermal efficiency, heat management, and reducing emissions. The association is drawing up a research roadmap charting a path involving, notably, bringing new research topics such as CO_2 recovery and reuse to the fore to enable automobile, industrial machinery, agricultural machinery, and other power sources to achieve zero emissions in 2050.

(2) Zero Emission Mobility Power Source Research Consortium: The consortium launched its activities in April 2020 under the slogans of *Promoting advanced research across a broad range of scientific and technological fields*, and *Nurturing human resources through collaborative industry–academia research*. It currently has 106 academic members, is working to achieve zero emissions for mobility through research on power sources centered on engine systems. Industry–academia collaboration is stimulated through friendly competition by providing a forum for academic members to engage in discussions on the same footing as the AICE-led corporate members.

5. 2. Research Papers

This section briefly describes the 2020 JSAE Awards-winning papers that are closely related to this article.

(1) Study of Engine PM Emission Mechanism under Low Temperature Transient Condition and PN Reduction Technology for Direct Injection Gasoline Engines: Imaoka et al. used in-cylinder visualization and transient conditions tests to assess the mechanism underlying the increase in PN emissions during steady state emissions test cycle evaluations. The carryover fuel accumulated during idling between engine start and acceleration forms a liquid film, resulting in a pool fire that generates PN during the first acceleration. Measure to decrease PN emissions include shortening the duration of the pool fire by retarding the ignition timing to delay the arrival of the flame at the piston stop surface, as well as lowering the combustion temperature by expanding the valve overlap to increase residual gas. Optimizing the fuel injection timing to decrease the amount of carryover fuel itself is another possible solution that can be combined with other measures to significantly reduce PN.

(2) Combustion Technologies in High Compression Ratio Engine Using High Pressure Gasoline Injection: Kaminaga et al. presented a method of using high pressure fuel injection to achieving full load thermal efficiency equivalent to that currently seen at a compression ratio of 14 using an actual engine with a compression ratio of 17. High compression ratio engines require overcoming the issues of pre-ignition and knocking. This was accomplished by placing 120 MPa high pressure injectors and the center of the combustion chamber, using piston cavities to guide the spray, and setting two spark plugs in the middle of the injectors to form the mixture in a short time and achieve early combustion. Reopening the exhaust valve during the intake stroke to introduce exhaust emissions realizes stable HCCI combustion, significantly enhancing thermal efficiency over a broad partial load range without sacrificing performance in the high load range.

(3) Achieving a Brake Thermal Efficiency of 40% Using Various Core Technologies in a Horizontally-Opposed Engine for Hybrid Vehicles: Nakayama et al. not only intensified tumble by laying the intake port angle sideways and redirecting air flow along the pent roof, but also focused on the quality of that tumble. They applied multipoint measurements using laser Doppler velocimetry (LDV) to measure the distribution of the rate of air flowing through the combustion chamber and evaluate tumble quality. Under conditions with a rapid flow at the sides of the combustion chamber, flows merge at the edge of the exhaust side, forming a flow the moves toward the center of the chamber. Since delays in localized flame propagation have an adverse impact on combustion, a uniform speed for the tumble flows at the center and each side of the chamber is preferred.

(4) Development of New 2.0-Liter Gasoline Engine That Uses Spark Controlled Compression Ignition: Sueoka et al. proposed spark controlled com-

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved

pression ignition (SPCCI), which uses a spark plug as the means of controlling combustion ignition (CI) combustion, producing the world's first mass-produced passenger vehicle gasoline engine achieving lean burn through compression ignition. In SPCCI, the spark ignition (SI) combustion triggered by the firing of the spark plug further compresses the air-fuel mixture in the combustion chamber, producing a mixture suited to CI combustion. The variation in combustion caused by changes in intake temperature, an issue in CI combustion, can then be controlled by regulating the ignition timing. The more abrupt combustion of SPCCI compared to previous SI combustion makes NVH an issue, which the SKYACTIV-D addresses though the Natural Sound Smoother (NSS) and engine encapsulation, as well as by lowering the cylinder pressure level (CPL) within the tolerance limit through precise combustion control provided by sensors inside each cylinder. The use of SPCCI combustion in the SKYACTIV-X significantly improves fuel economy at low- to medium loads while achieving a torque improvement of 10% or higher in all ranges compared to the SKYACTIV-G.

5. 3. Jet Ignition System

This ignition system relies on spraying jet flame from a sub-chamber placed in the combustion chamber to trigger rapid combustion of the air-fuel mixture in the main chamber. In combination with a combustion of λ =1, it contributes significantly to improving thermal efficiency. Jet ignition systems come in active and passive variations. The former sets injectors in the sub-chamber to send out fuel directly, while the latter relies on the flow in the cylinder to push the air-fuel mixture into the sub-chamber. The active variation is preferred when the system is combined with lean burn. Research is pursued by many organizations, and in 2020, Maserati launched the Nettuno, the world's first V6 gasoline engine featuring a jet ignition system installed in a commercial vehicle.

5. 4. STARC Concept

Developed to enhance thermal efficiency, the Strong Tumble and Appropriately stretched Robust ignition Channel (STARC) concept realizes extremely lean burn through a high EGR ratio that reaches 30% and a leaner mixture exceeding λ =2. Achieving stable combustion under extremely lean conditions requires meeting the following requirements: (a) a strong tumble flowing from the top of the intake port to the exhaust pent roof without detaching, (b) maintaining tumble flow until the ignition timing, and (c) stabilizing the flow moving toward the spark plugs.

No-valve seat technology based on cold spray and an expanded valve included angle was used as a means of achieving requirement (a). Removing the valve seat increased the design flexibility of the intake port, making it possible to eliminate the unevenness between the port and the combustion chamber and obtain a smooth intake air flow. The trade-offs found in previous models were mitigated, resulting in both high flow and high tumble, and achieving a stable flow with a high velocity near the exhaust pent roof.

Design guidelines calling for maintaining the center of the tumble swirl in the middle of the combustion chamber with the central axis of the tumble forming a straight-line without distortion were established to maintain tumble until the ignition timing (requirement (b)). Pistons with rugby ball-shaped cavities without irregularities thanks to the removal of the valve recesses were combined with a combustion chamber featuring a low aspect ratio.

Depressions designed to regulate the tumble downward were formed at the top surface of the combustion chamber (requirement (c)) and appropriate spark plug placement enabled the discharge channels to expand without being impeded by the exhaust pent roof wall, and the stable formation of an early flame kernel. The use of EGR to achieve a thermal efficiency of 43% under extreme lean burn conditions in a multi-cylinder engine has been demonstrated. The next step will involve achieving a thermal efficiency of 50% by combining technologies to reduce cooling loss with technologies that recover exhaust energy under weak stratified lean burn that exceeds λ =2.

References

・Turushima, T., Future Internal Combustion Engine Concept Dedicated to NISSAN e-POWER for Sustainable Mobility, 29th Aachen Colloquium Sustainable Mobility (2020)

Copyright© 2021 Society of Automotive Engineers of Japan, Inc. All rights reserved