The New Engine for Accord Hybrid and Study of the Turbocharging Direct Injection Gasoline Engine of Small Diameter of Cylinder

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Summary

The new 2.0L gasoline engine for ACCORD Hybrid was developed as a next-generation Honda engine series. This engine's features are low fuel consumption and good emission performance. Variable valve Timing and Electric Control (VTEC) system is applied to this engine, such that two characteristic intake cam profiles are available, which are called output cam and fuel economy (FE) cam. The output cam provides narrow duration, used for power and engine starting. The FE cam has a wide duration, to realize an Atkinson cycle effect by late intake valve close timing (IVC). Cooled exhaust gas recirculation (Cooled-EGR) is applied to this engine. Low fuel consumption is achieved by combining VTEC and cooled EGR. This new engine series is already utilized and in addition, we are developing downsized turbocharged engines. One engine of them has 73 mm bore diameter which is same as an existing natural aspirated engine and side direct injection concept, in consideration of mass-production efficiency. Although it is in the middle of development, sufficient performance of combustion cylinder was attained in spite of small bore and side direct injection by optimizing intake port and injector spray form.

1 Introduction

In the evolution of global motorization, providing products which is considered about environment is a responsibility of automobile companies. Each company has been working hard to develop a variety of technologies, such as fuel cell vehicle (FCV), electric vehicle (EV), hybrid electric vehicle (HEV), and downsized turbo, etc. Honda has been selling HEV that have Integrated Motor Assist (IMA) system. This system has the advantages of being simple, compact and lightweight, and suitable for small cars. At the end of 2012, Honda started selling ACCORD Plug-in Hybrid with a new two-motor hybrid system[1] which raised its power. This system can be applied to medium-size cars. We developed new gasoline engine for ACCORD Plug-in Hybrid. It is a part of Honda's new engine series "Earth Dreams Technology" (Fig.1). On the other hand, there is downsized turbo as a means of improvement in fuel consumption which is different in HEV. We are developing downsized turbo engine based on the engine developed by Earth Dreams Technology. The bore diameter is 73 mm which is the size which generally chooses center injection. Since the required function was filled only with side injection in 73mm bore, it is introduced here.

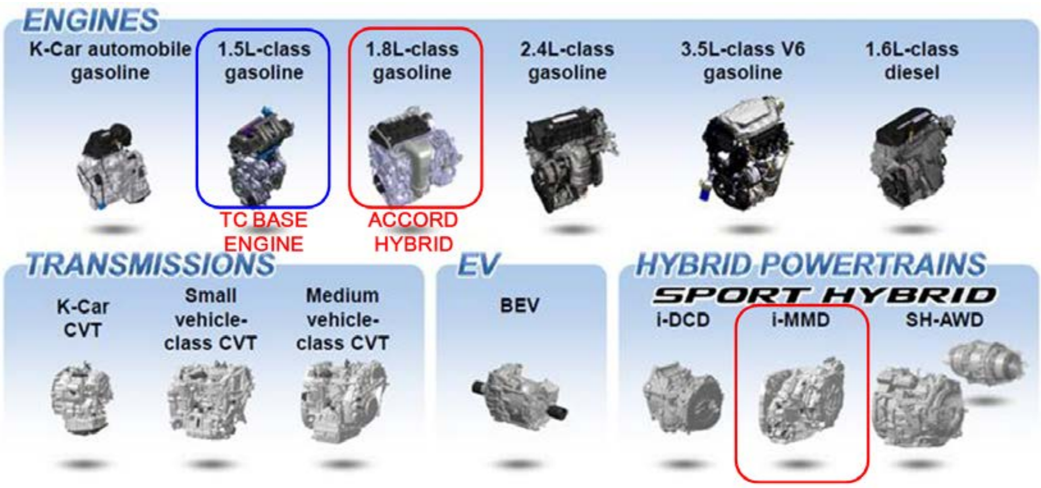


Fig. 1: Earth Dreams Technology

2 New 2.0L Gasoline Engine for Accord Hybrid

2.1 Drive mode

During the development of this engine, our most important issue is fuel consumption. To improve fuel consumption of hybrid vehicles, it is needed to understand the engine operation area. That area is determined by drive mode. The Accord hybrid has three different drive modes as shown in Fig.2. The three drive modes are EV drive mode, hybrid drive mode and engine drive mode. In EV drive mode, engine is not operated. The vehicle runs by only battery energy. Hybrid drive mode is used in normal driving, and the vehicle runs by electricity generated by the engine. In this mode, the engine is running at the optimum fuel consumption line. That is in high load domain. Engine drive mode is used at high speeds cruising. High speeds means approximately over 80 kilometer per hour. At high speeds cruising, engine direct drive is more efficient than using motor in this hybrid system. At this time, the engine runs on middle load.

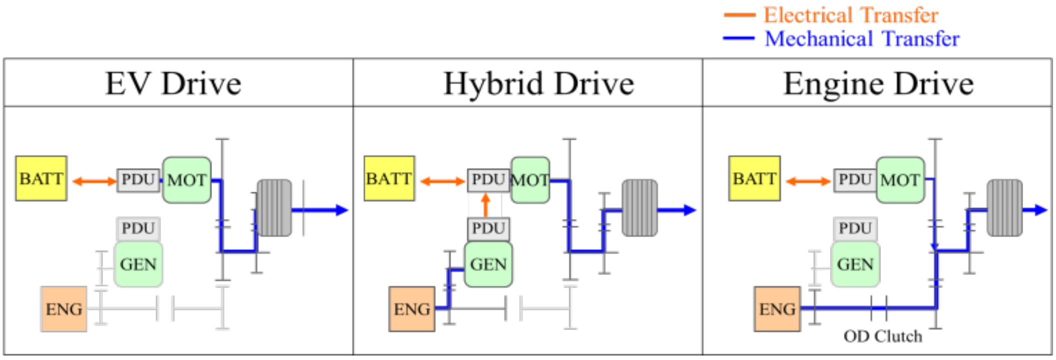


Fig. 2: Drive mode of Accord Hybrid

2.2 Engine Specification

The engine we developed is shown in Fig.3. The main specifications are shown in Fig. 4 compared to Honda’s current 2.0L engine. Both engines have same bore pitch. The newly developed engine features DOHC, VTEC system, and electric valve timing control (EVTC) with intake side. In exhaust side, we adopted press type rocker arm with Hydraulic Lash Adjuster (HLA), aimed at light weight and reduction of friction. In order to compensate the flow performance by high tumble port adoption (after-mentioned), the intake valve diameter was expanded by 1mm. Cylinder offset is changed in order to lower engine height. The diameter of a crank journal is made small to reduce the friction loss. Compression ratio is 13, we adopted Atkinson cycle and cooled-EGR system. An electric water pump (EWP) is adopted for improvement of fuel consumption. We chose port injection against direct injection because of the balance of the output performance, fuel consumption, and cost which are demanded.

Fig. 3: New 2.0L gasoline engine for Accord hybrid

Engine Type	New development	Current
Cylinder configuration	Inline 4	Inline 4
Bore x Stroke (mm)	81 x 96.7	81 x 96.9
Displacement (cm^3)	1993	1998
Cylinder offset (mm)	6	12
Crank journal diameter(mm)	50	55
Compression ratio	13.0	10.6
Valve train (intake)	VTEC & E-VTC	VTEC
Valve train(exhaust)	Finger rocker arm (with HLA)	Rocker arm (with rocker shaft)
Number of valves	4	4
Valve diameter (mm) Intake/exhaust	33/26	32/26
EGR system	Cooled	Hot
Water pump	Electric	Mechanical
Fuel injection type	Port injection	Port injection
Fuel	Regular	Regular
Maximum Power	105 kW	115kW
Maximum Torque	165 Nm	192Nm
Emission Regulation	SULEV20	EURO5

Fig. 4: Specifications of new 2.0L engine

2.3 Engine Performance

Engine performance is shown in Fig.5. The maximum power is 105kW at 6200rpm and the maximum torque is 165N·m over 2500rpm. The BSFC contour is shown in Fig.6. Engine operating area is in low fuel consumption zone. We achieved BSFC 214g/kWh at 2500rpm and 120Nm. At that point, thermal efficiency is 38.8%.

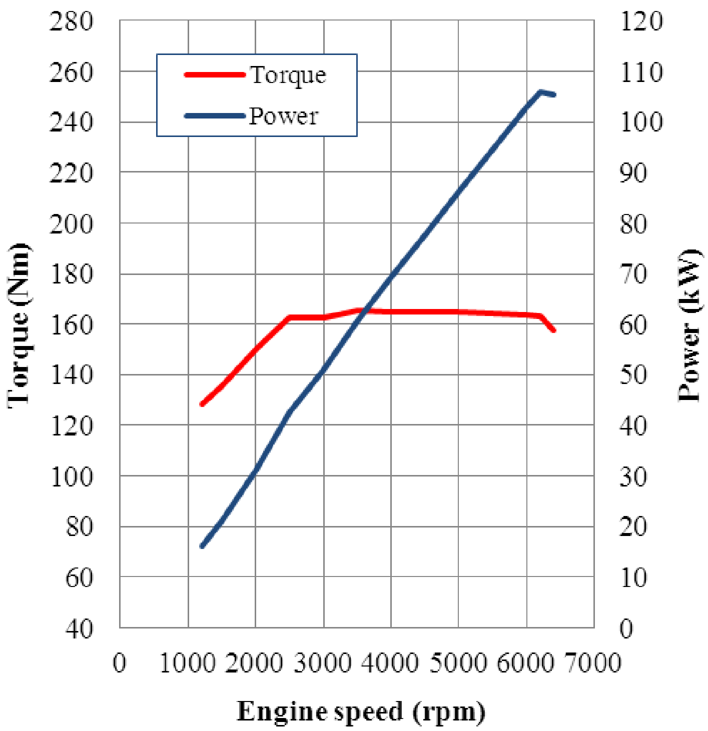


Fig. 5: Engine output performance

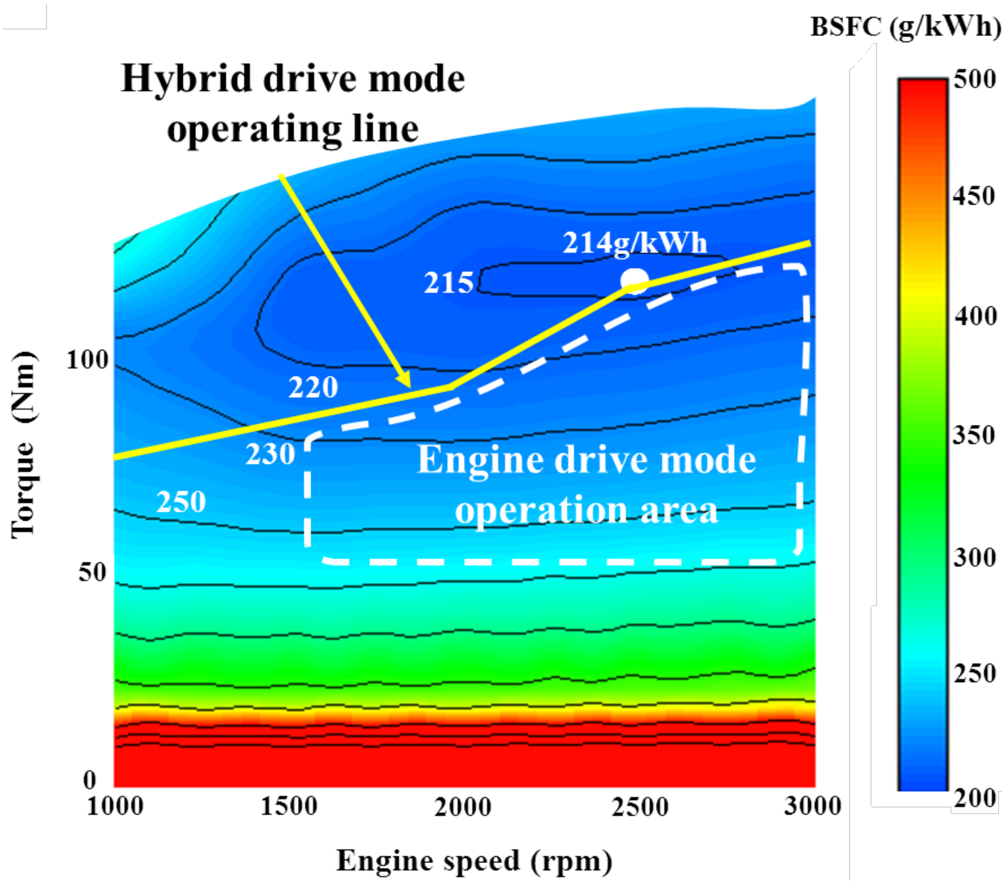


Fig. 6: Fuel consumption performance (contour of BSFC)

Fig. 7 shows the new engine's exhaust system. The engine uses a new control [2] that utilizes the characteristics of the hybrid system in order to efficiently warm up the two catalysts by adjusting the amount of power generated after engine start. Although the chapter of VTEC explains for details, feed emissions are also reduced to a low level through the use of output cams with narrow opening angles at engine start. As a result, the PHEV specification for the North American market is the first vehicle to conform to the SULEV 20 standard at first in the world.

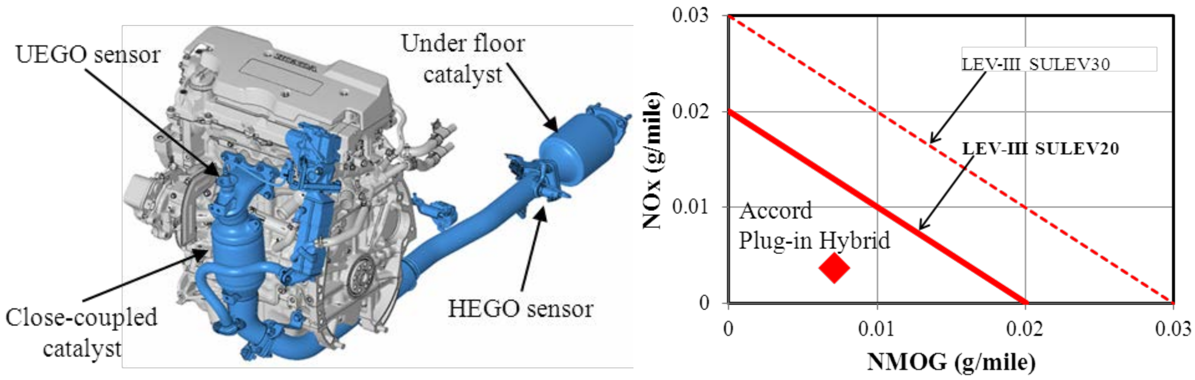


Fig. 7: Exhaust system and emission performance

2.4 VTEC Technology

We adopted VTEC system to intake valve train. VTEC is a well-known technology at Honda. This structure is shown in Fig. 8. It has three cams and three rocker arms per one cylinder. Cam of both sides is output cam, and center is fuel economy (FE) cam. At the time of output cam use, VTEC is off, and three rocker arms operate separately. At the time of FE cam use, VTEC is on, three rocker arms are combined by synchronized pins. In order to enable a change in the low oil pressure state after starting, the hydraulic-hydraulic type VTEC mechanism [3] is adopted.

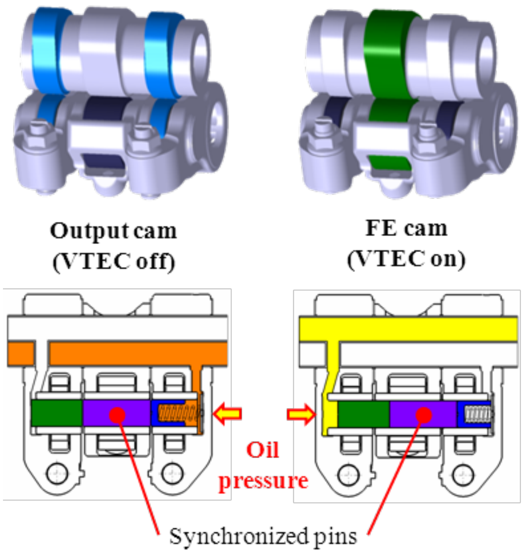


Fig. 8: VTEC structure and moving action

Each valve lift curve is shown in Fig. 9, and the corresponding operation area is shown in Fig. 10. The opening duration of the Output cam is narrow (196 degree @ 1 mm valve lift), it is used at the time of engine starting and high output necessity. The one of the FE cam is wide (240 degree @ 1 mm valve lift), it is used at the time of normal driving when low fuel consumption is demanded.

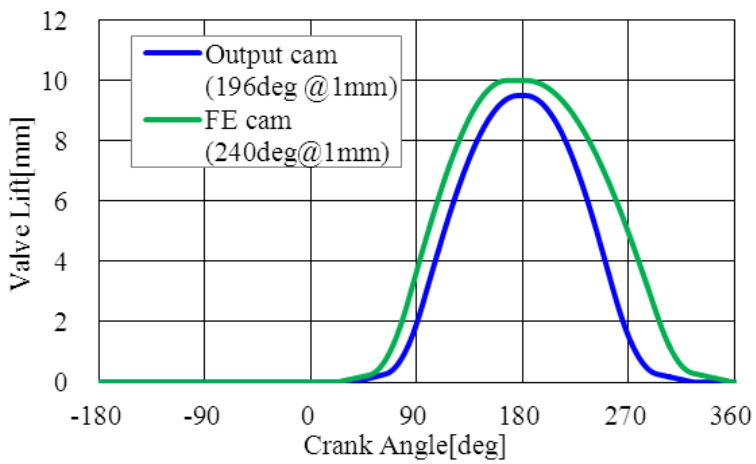


Fig. 9: Intake valve timing (Output cam and FE cam)

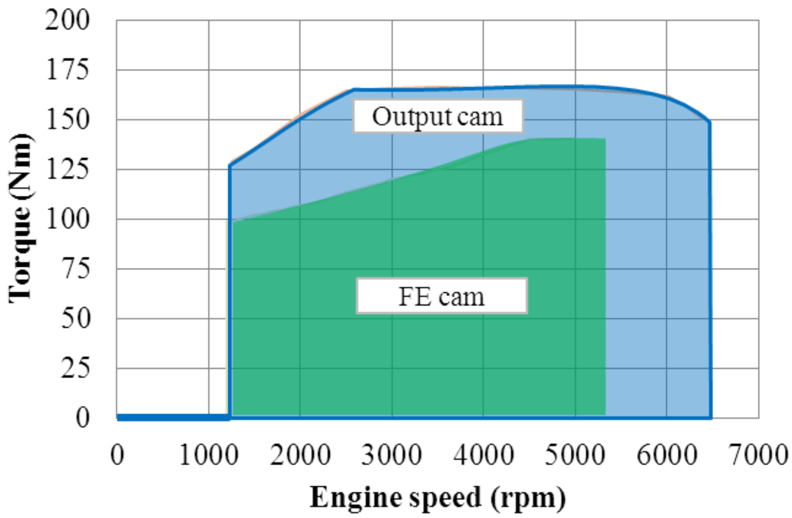


Fig. 10: VTEC operation

2.5 VTEC Effect

We verified the effect of VTEC from a viewpoint of an output, fuel consumption, and feed emission. First, the difference in the output of two cams is shown in Figure 11. FE cam cannot be used at high engine speeds because of its wide duration. Maximum output is achieved by using the Output cam. At less than 3000 rpm, difference of maximum torque is only about 5Nm. But fuel consumption is bad at the point of maximum torque by using FE cam. The FE cam has much return flow back into the intake because of its wide duration. In order to get high torque, it is needed to reduce EGR. So output cam has good fuel consumption in high torque area, VTEC operation is as shown in Figure 10.

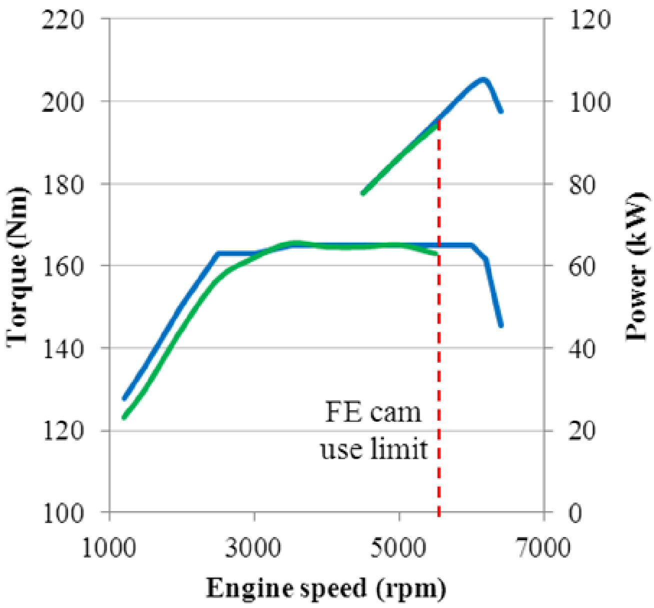


Fig. 11: Output performance of each cam

Next, the result of the fuel consumption by each cam is shown in Figure 12. At high load each BSFC is equal, but in another area FE cam is good. It is because FE cam is wide duration, so pumping losses can be reduced by effect of Atkinson cycle.

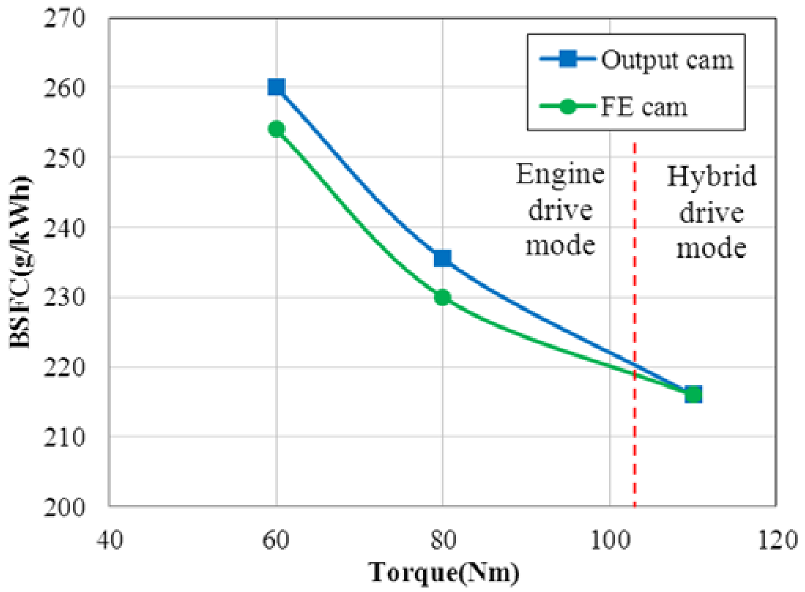


Fig. 12: Fuel consumption of each cam (at 2000rpm)

Last, the result of feed emission is shown in Figure 13 and 14. Fig. 13 shows each covariance of IMEP to ignition timing at same IVC. Since the Output cam has small valve overlap, its combustion is more stable than the FE cam. So, the Output cam can permit an increased retard of ignition timing. Fig. 14 shows the amount of HC to the ignition timing of each cam. The influence of a retard limit is very large, and the amount of HC of the Output cam is a half of the FE cam. The Output cam contributes to reduction of feed emission at engine start.

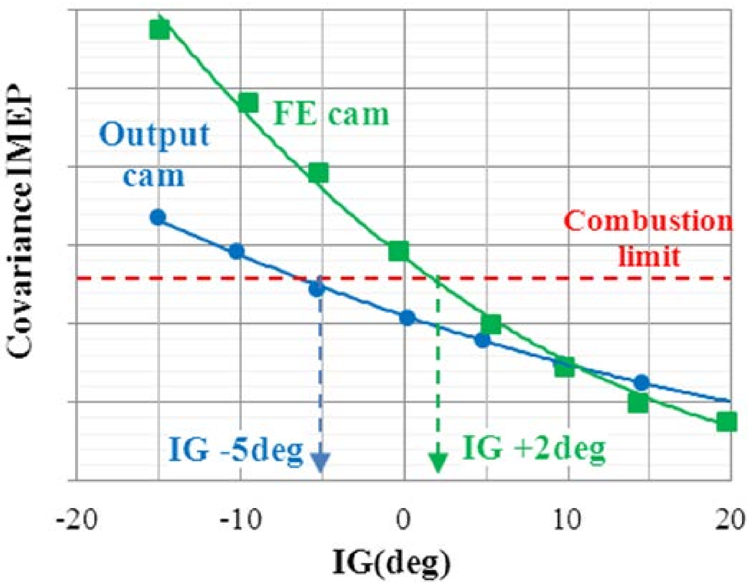


Fig. 13: Combustion limit of each cam

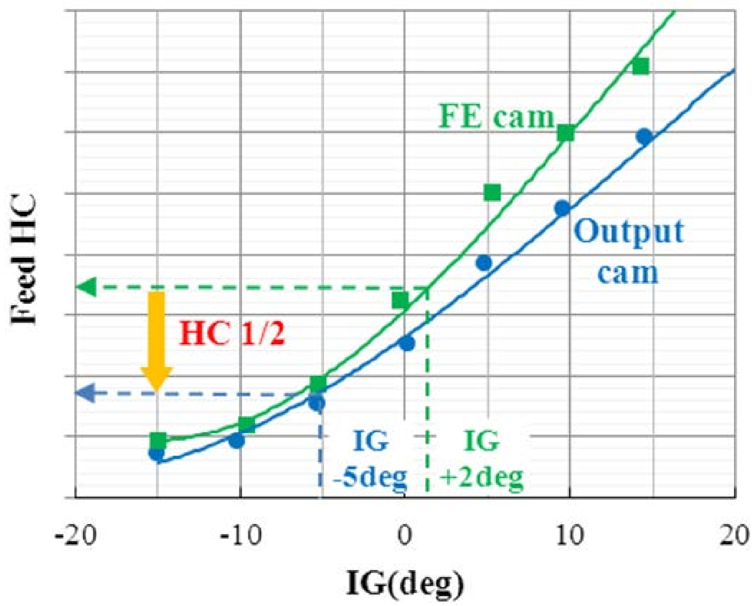


Fig. 14: Feed HC of each cam

2.6 Cooled-EGR

The operating range of a hybrid car engine is limited to high load, so adopting COOLED-EGR for the improvement in fuel consumption is reasonable. [4] However, cooled EGR makes combustion speed slower. In order to maximize the effect of cooled EGR, it is necessary to improve combustion. We designed high tumble inlet port (Fig.15). In order to strengthen a tumble, it aimed for the mainstream to flow into the exhaust gas side of a combustion chamber. The side view of the port was changed and it designed in edge form below the port. The port flow simulation result in developed port and current port is shown in Fig.16. The flow of the valve bottom was reduced and the mainstream flows through the upper part, we could generate strong tumble in the cylinder. The tumble ratio of developed port is 1.40, that of current port is 0.73. The result of real firing test is shown in Fig.17. Covariance of IMEP is improved by strong tumble ratio. So we get 5g/kWh improvement of ISFC at best point by adopting this port.

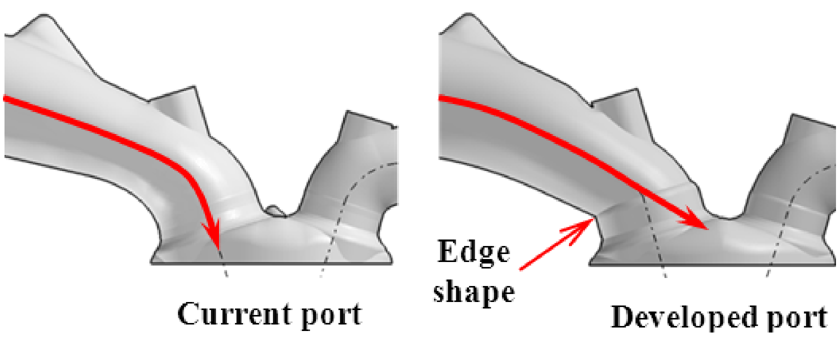


Fig. 15: Tumble port shape

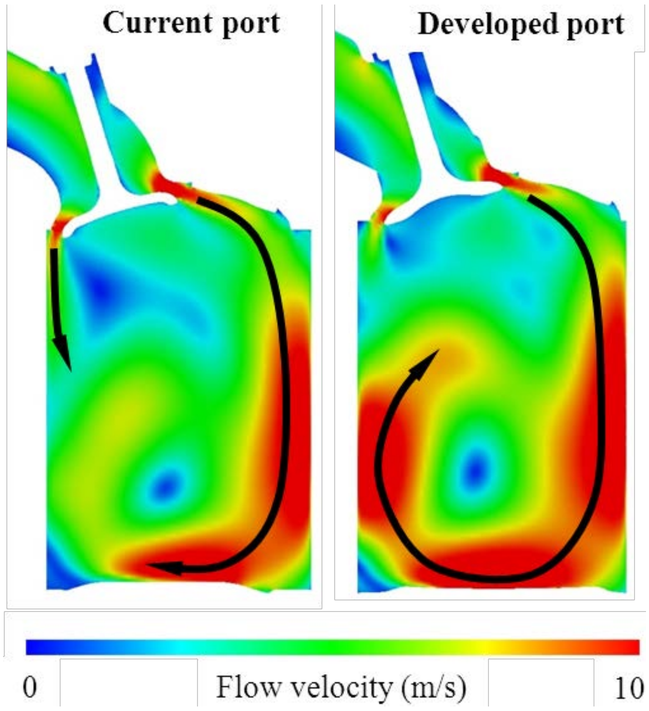


Fig. 16: Flow simulation result

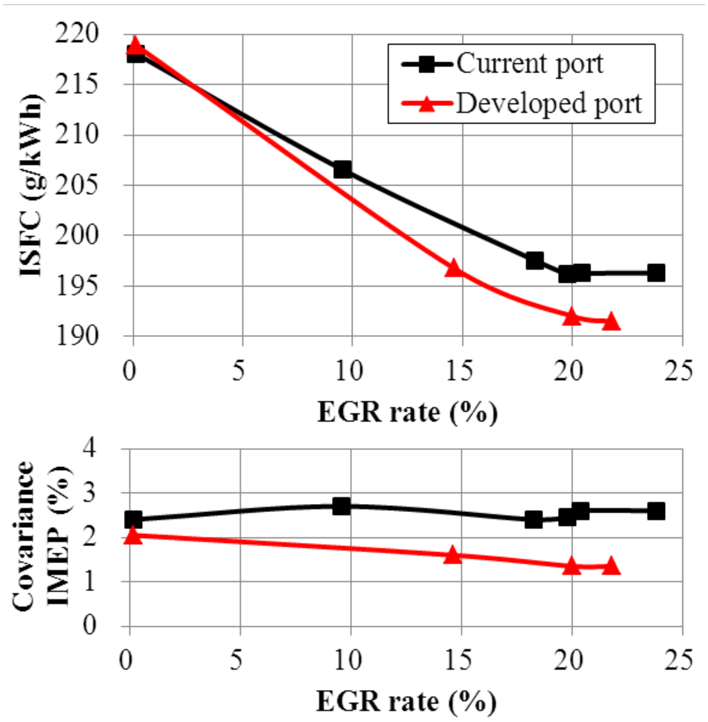


Fig. 17: Effect of high tumble port

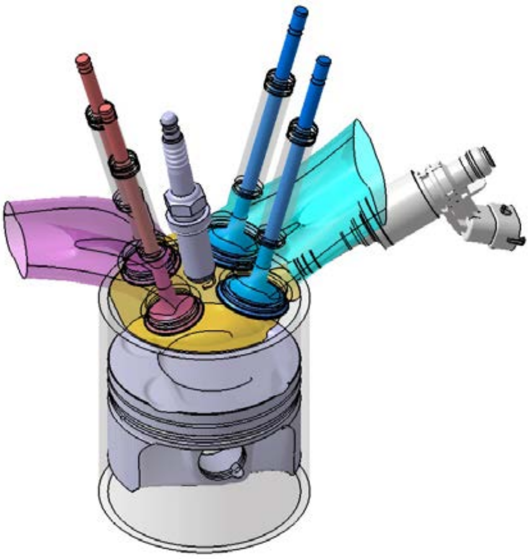
The VTEC system was combined with a new hybrid system i-MMD. Moreover, the effect of cooled EGR was maximized by application of the tumble port, and fuel consumption has been improved. As result, in outputs, and all the fuel consumption and emission, the high performance was attained and it contributed to the high marketability of the Accord hybrid.

3 Study of Small bore and Side Injecton

From here, the contents which attained the required function by 73mm bore and side direct injection in the developing turbo engine are introduced.

3.1 Cylinder Specification

The combustion chamber configuration and specifications of a turbocharged engine currently under development are shown below Fig.18. We chose 73mm bore diameter which is same as an existing engine because of manufacturing efficiency. Stroke is same as the 1.3L engine. The valve angle and the injector angle are using the existing engine. Side injection was adopted, the 28mm of intake valve diameter and the 25mm of exhaust valve diameter were secured, and output potential was given. In such conditions, we optimized the intake port. Details are shown below.



Cylinder Geometry	This Engine	1.5L-DI	1.3L-PI
Bore (mm)	73	73	73
Stroke (mm)	78.7	89.4	78.7
Intake valve diameter (mm)	28	29	29
Exhaust valve diameter (mm)	25	25	25
Intake valve angle (degree)	15	15	15
Exhaust valve angle (degree)	15	15	15
Spark plug angle (degree)	12	12	12
Side injector angle (degree)	27	27	-

Fig. 18: Cylinder specification of the turbocharged engine under development

3.2 Port Design Background

Although it is important to strengthen tumble for combustion improvement, it disagrees with flow performance. So it is difficult where to set a target. We arranged the test result for goal setting. (Fig.19) The X-axis is a tumble ratio and the Y-axis is ISFC. Red shows NA engine's result, blue is TC engine's result. These are the results in an operating range with best ISFC. The following is an operating condition of NA engine. Compression ratio is 13.5, engine speed is 2500rpm, BMEP is 750 bar, EGR rate is 25%. For the TC engine, compression ratio is 10.5, engine speed is 2000rpm, BMEP is 1200 bar, and no EGR. In the NA engine, ISFC gets worse suddenly from a certain tumble ratio. We consider that cause is a heat loss increase by too strong tumble flow in cylinder. The introduced hybrid engine's intake port was designed targeting this bottom. Developing TC ENG aimed at the tumble ratio 2.0 from this result.

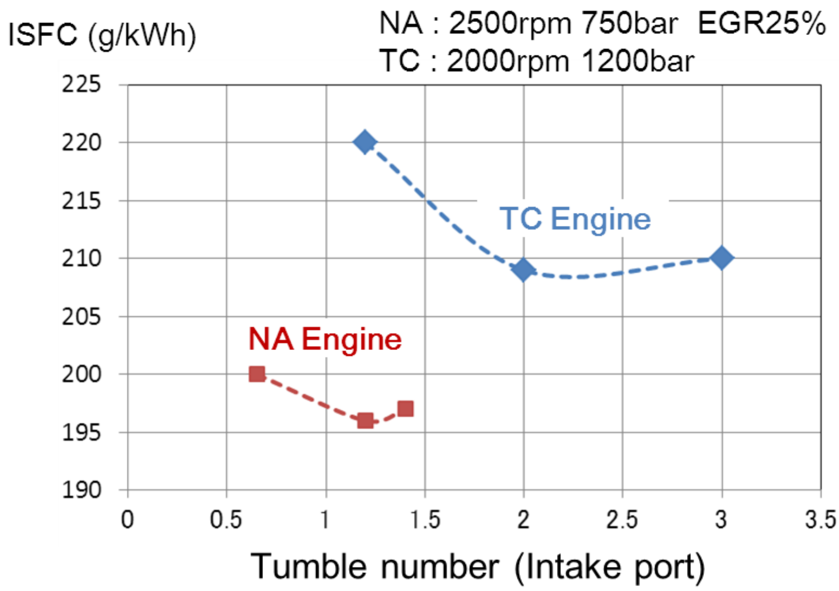


Fig. 19: Relationship between tumble and ISFC at NA and TC engine

3.3 Intake Port Optimization

The intake port shape of the existing 1.5 L-DI engine which is base of examination and development engine are shown in Fig. 20. The optimization to TC engine was performed for mass-production machining efficiency reservation, without changing the angle of a valve and injector. In order to reduce fuel adhesion on intake valves, the diameter of intake valve was changed into 28 mm from 29 mm, and the valve seat position was moved to the 2mm upper part, without changing an angle. Tumble was strengthened with making port shape flatter than a base shape. 1mm reduction of the diameter of a valve also contributes to tumble strengthening. The calculation result of the tumble number in the crank angles 360-720 degrees is shown in Fig. 21. The black line is the base engine, The blue line is this port. The desired value of the turbo engine (green line) was able to be attained. The total tumble ratio was set to 2.0 and protected the target set up by 3.2.

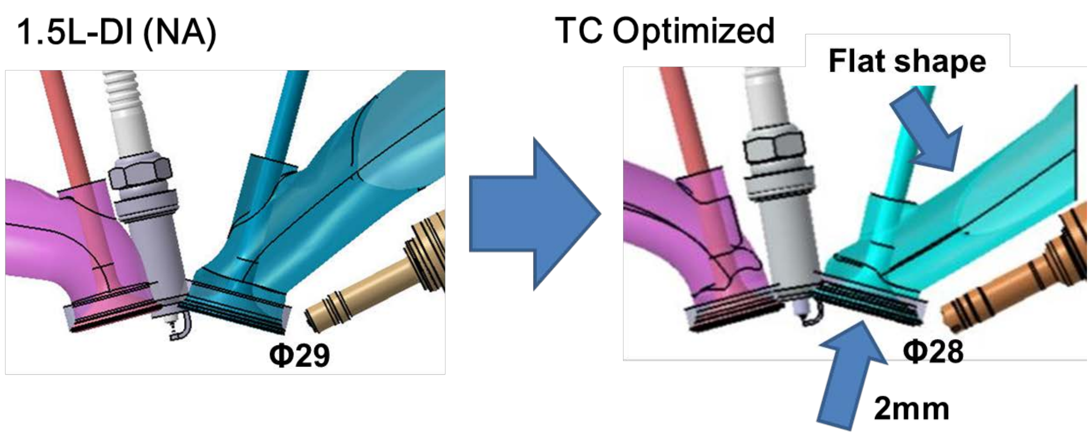


Fig. 20: Intake port design

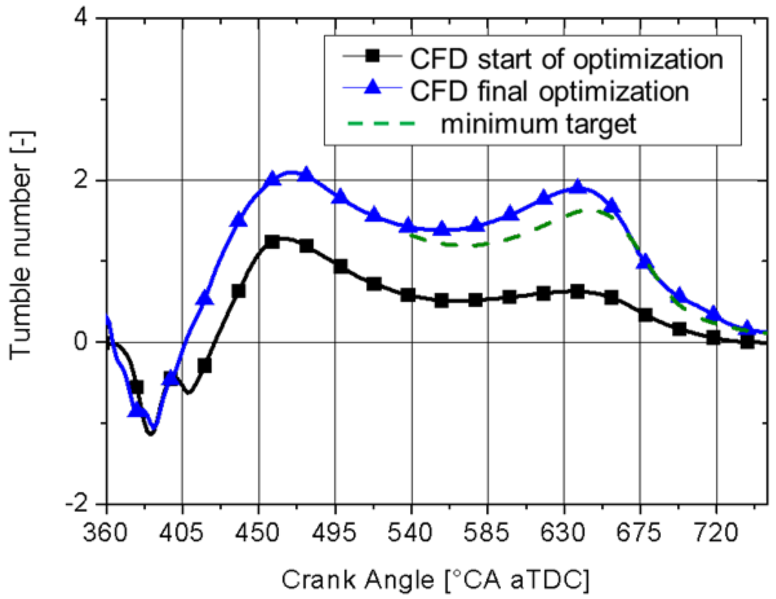


Fig. 21: Tumble performance

3.4 Combustion Speed

The achievement result of burning velocity is shown in Fig.22. The left graph shows burn delay and the right graph shows the burn duration 5-50%. Black points show the CAE result of base engine and, blue points indicate the CAE result of development TC engine, red points are actual test result. The green line is the desired value for a TC engine. The combustion performance needed was attained by having strengthened tumble.

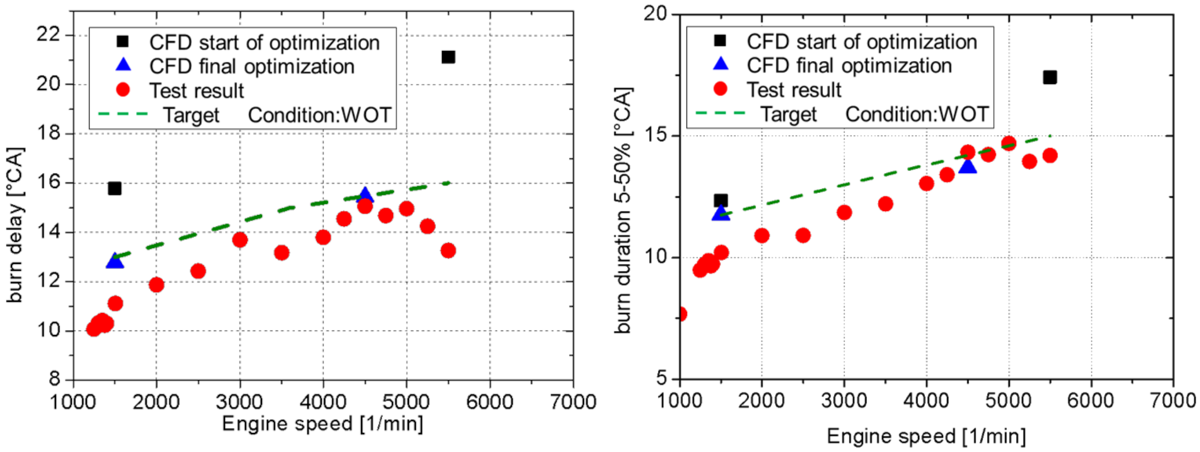


Fig. 22: Burn delay and burn duration 5-50%

3.5 Injector Spray Form

The injector spray form is most important point in order to satisfy each function in small bore and side injection. Liner and piston impingement should be avoided for which usually a rather narrow spray pattern is favoured. But, a narrow spray pattern may cause the spray to collapse and produce bad mixture formation. We examined many spray forms by optical engine analysis. [5,6] A result is shown in Fig. 23. The X-axis is shown evaporation time scale about droplet, left-side is better. The Y-axis is a numerical value showing fuel adhesion with cylinder wall, bottom is good. Lower left area is the temporary target in this engine development. The star shows a mass-production TC-DI engine which suits EURO5, so the target is set as the enough high level. Each spray form was checked on different spray timing. Operating conditions are 2000rpm and 12bar. As a result of measuring, we finally chose target B. The reason for having chosen not A but B is because the performance of fuel adhesion with cylinder wall is more important in small bore condition.

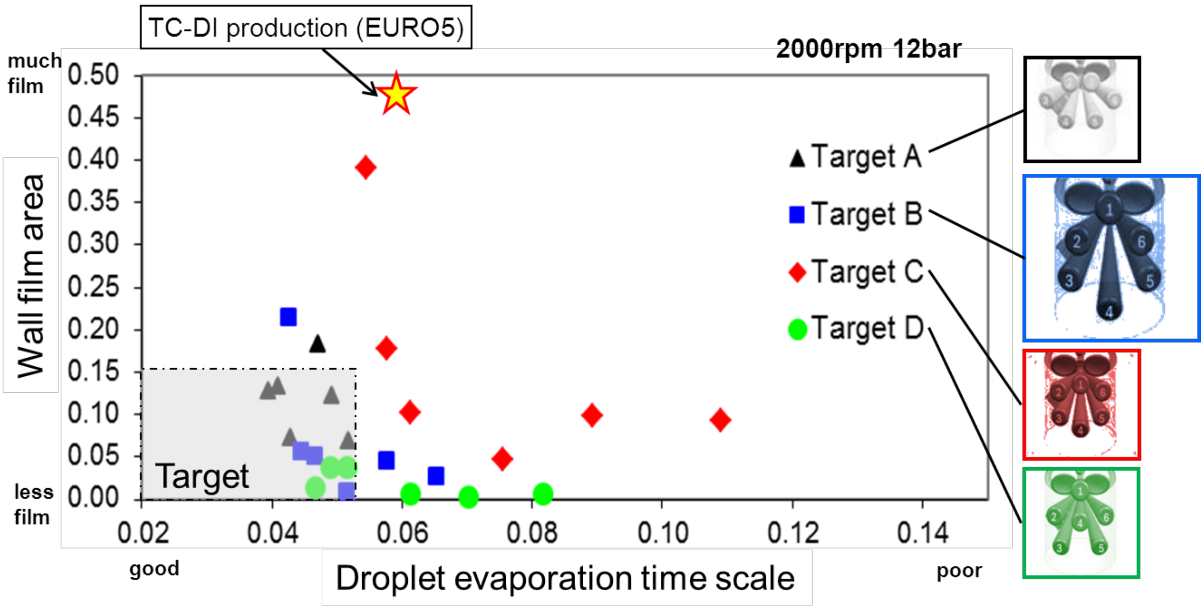


Fig. 23: Injector spray form optimization

3.6 Oil Dilution

The test result of oil dilution which is of concern with a small bore is shown in Fig. 24. The X-axis is the relative air fuel ratio lambda and the Y-axis is the dilution rate. As a result of optimization of intake port and injector spray, an oil dilution level in the middle of the scatter band was attained as prediction of the original CFD.

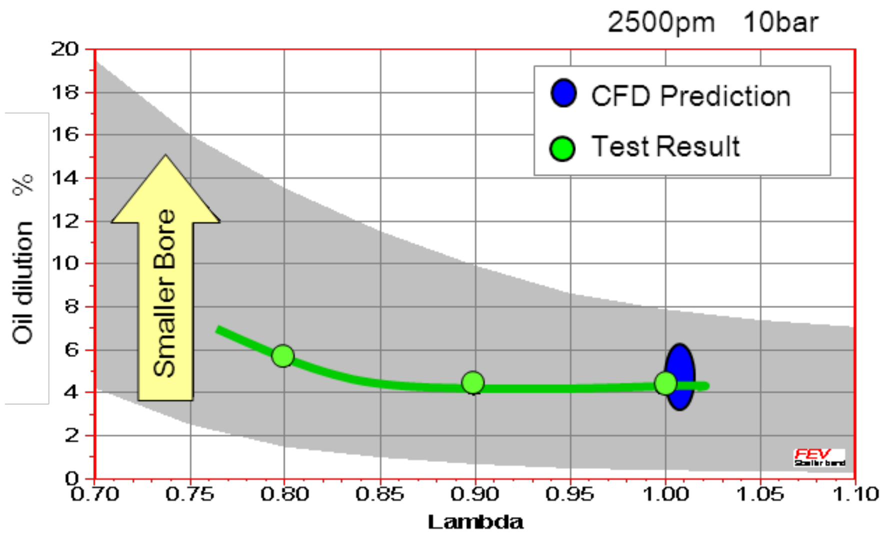


Fig. 24: Oil dilution performance (CFD prediction and test result)

3.7 EURO6 Regulation

The achievement situation of PN to EURO6 regulation of this engine is shown in Fig. 25. As a result of optimizing intake port and injector spraying, EURO6-b is satisfied. With detailed setup of injection control in the future, we will develop aiming at EURO 6-c achievement only with the side injector.

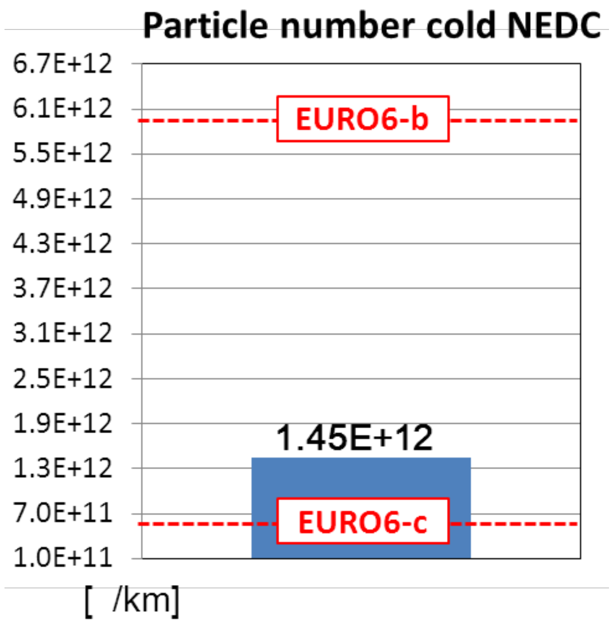


Fig. 25: For Euro6 regulation

As mentioned above, the functional prospect with only side injector was acquired to a 73mm bore diameter. We think that the combustion chamber specifications which secured manufacturing efficiency and output potential have been designed.

4 Conclusion

1. VTEC was adjusted to i-MMD hybrid system. It contributed to the following performance achievement.

   Maximum Output: 105kW, Minimum BSFC: 214g/kWh

2. Adoption of high tumble intake port made fuel consumption effect of Cooled-EGR maximized.

3. Though it is the side direct injection in the small bore diameter, each function needed was able to be formed by optimizing intake port and injector spray form.

5 References

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