The Development of a New Turbocharged Engine with an Intelligent Variable Valve Timing System and New High Efficiency Turbocharger

連続可変バルブタイミング機構付きターボインジンの開発*

The 1JZ-GTE engine has been modified by the addition of an Intelligent Variable Valve Timing System (continuous wide range intake camshaft phasing control system) and a new high-efficiency turbocharger (CT 15B). The engine generates 50% more engine torque at low engine speeds, and turbo lag has been reduced by 50%, while allowing a 10% improvement of fuel economy.

Key words: Gasoline Engine, Valvetrain, Turbocharger, Fuel Economy, Variable Valve Timing
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1. Introduction

In recent years, care for the environment, and efforts to help prevent global warming via the improvement of fuel economy have been considered an urgent social requirement. For turbocharged vehicles, an agreeable combination of nimble drivability and an appropriate level of responsiveness together with good fuel economy is desirable.

The adoption of a newly developed continuously variable valve timing mechanism (VVT-i) and a highly efficient turbocharger combines both power performance and low fuel consumption for this newly developed turbo engine.

A summary follows of the development of this version of the 1JZ-GTE engine.

2. Development Aims

To add to the existing favorable impression, a combination of good operability and responsiveness and economy, this next generation sports engine benefits from the development items listed below.

1.) Low to medium speed torque has been improved while ensuring high power output.
2.) Turbo response has been improved.
3.) Fuel economy has been improved.

3. Engine Summary

Using the existing engine as a base, a continuously variable valve timing mechanism (VVT-i) has been adopted for the intake camshaft together with the adoption of the newly developed CT15B model ceramic turbocharger. Also, because of the increase of the compression ratio, a further improvement of fuel economy was possible. Lastly, an electronically controlled throttle was adopted that achieves safe and smooth operation of the throttle.

Table 1: Main Data

Engine	1JZ-GTE	
	New	Previous
Displacement (cc)	2491	same
Configuration	In-line 6 cylinder	same
Combustion Chamber	Pentroof	same
Valve Mechanism	DOHC 4-valve	same
Fuel System	EFI	same
Fuel Requirement	Unleaded Premium	same
Compression Ratio	9.0	8.5
Bore x Stroke	86 x 71.5	same
Maximum Power (kW @ RPM) [PS @ RPM]	206 @ 6200 280 @ 6200	same
Maximum Torque (Nm @ RPM) [kgm @ RPM] {lb-ft @ RPM}	(378 @ 2400) [38.5 @ 2400] {278 @ 2400}	(363 @ 4800) [37.0 @ 4800] {268 @ 4800}
Fuel Consumption Rate (g/kWh @ RPM)	278 @ 2000	285 @ 2000
Size length x width x height (mm)	AT: 840 x 680 x 650 MT: 860 x 680 x 650	AT: 760 x 655 x 655 MT: 775 x 655 x 655

Diagram 1: Engine Cross-section

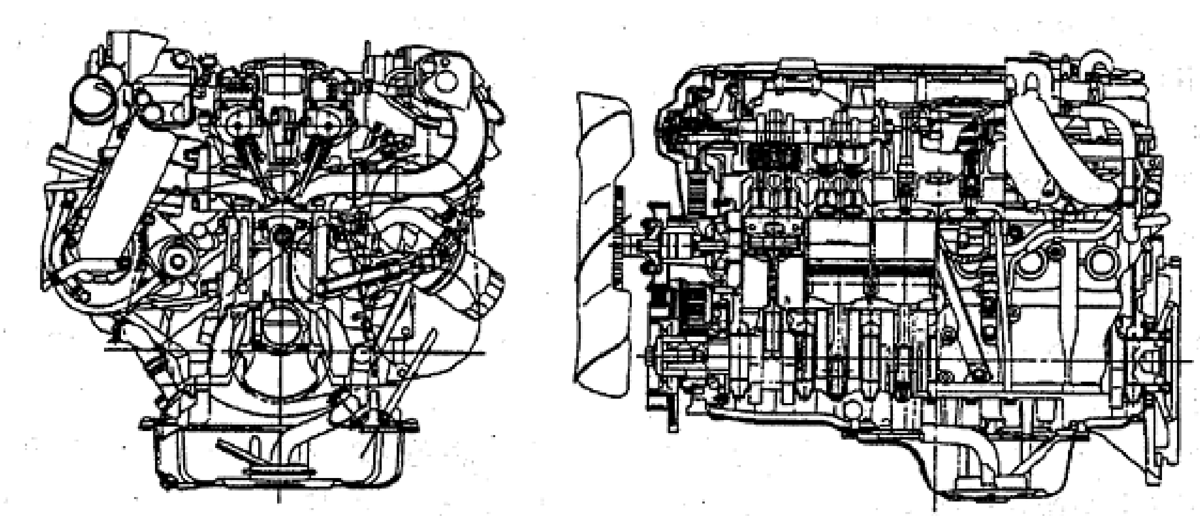
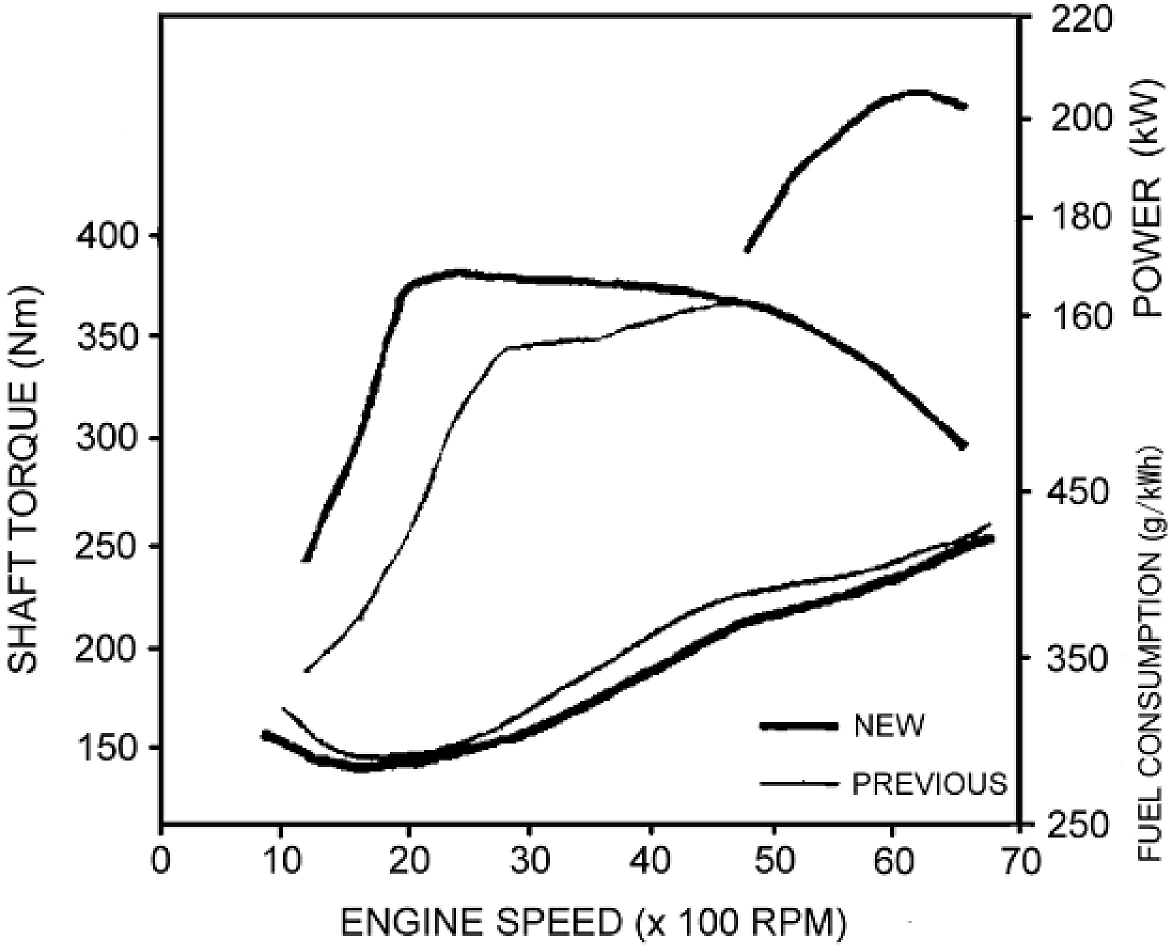


Diagram 2: Engine Performance Curves



4. Turbo System Examination

Table 2 shows the results of a comparative study of a turbo system that uses VVT-i
Low speed torque and turbo response have been improved due to the selection of a single medium sized turbo. The volume of the turbo air charge increases because the exhaust energy is increased along with a volumetric efficiency improvement due to adoption of VVT-i for this turbo engine. As a result, engine performance is improved. In this manner, VVT-i draws out the performance of the turbo; it is also an effective system for the improvement of efficiency.

Table 2: Comparison

	Conventional Twin Turbo	2-way Twin Turbo	With VVT-i		
			Conventional CT12A x 2	Small Type (CT7B) x 2	Mid-sized Type (CT15B) x 1
Peak Power	○	◎	◎	○	○
Maximum Torque	○	○	◎	△	◎
Low Speed Torque	△	◎	○	○	◎
Turbo Response	△	◎	○	◎	◎
Fuel Economy	△	△	○	○	○
Emissions	△	△	○	○	○
Cost	○	△	△	△	◎

Key:
◎ Best ○ Good △ Passable

5. Continuously Variable Valve Timing Mechanism (VVT-i)

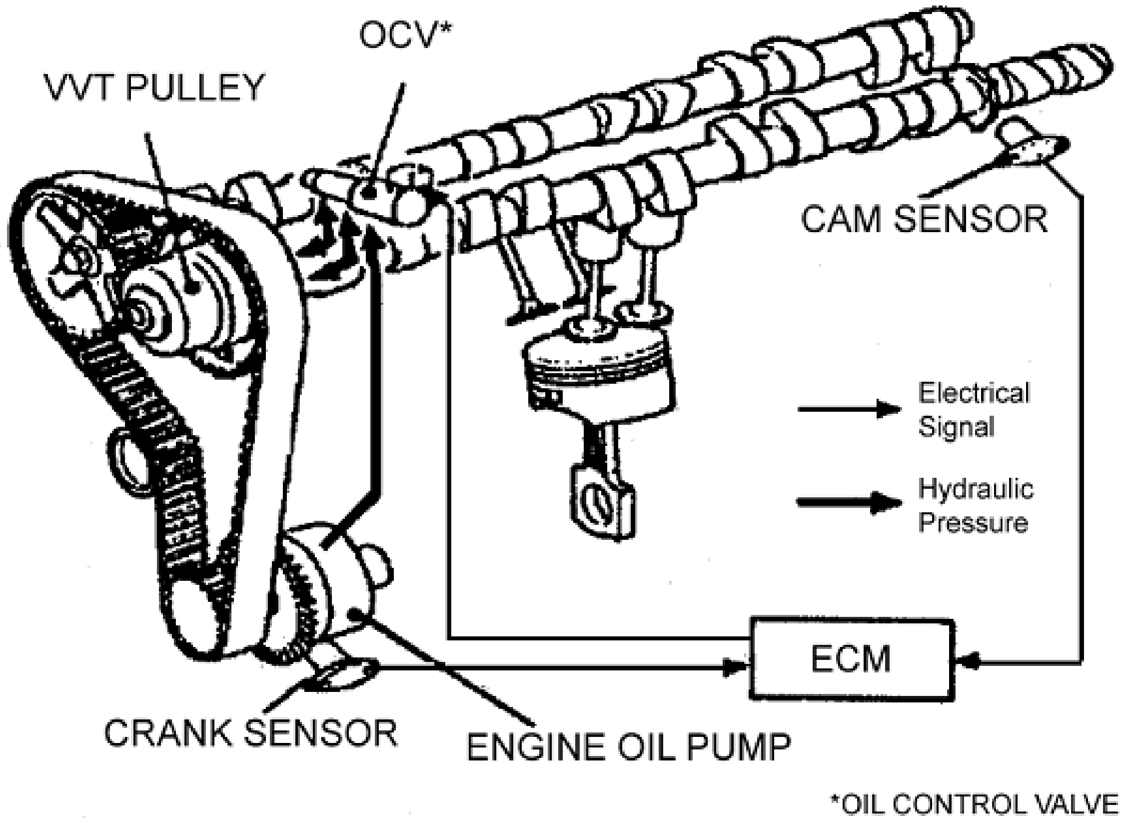
5.1 VVT-I System

The VVT-i pulley used for the previously announced 2JZ-GE engine is also used for this application. Diagram 3 shows a drawing of the VVT-i system.
Main configuration

1. An ECU that optimizes the valve timing for the engine operating conditions.
2. An OCV (Oil Control Valve) that controls the oil pressure according to the instructions of the ECU
3. A VVT-i belt pulley with a simple structure that changes the intake valve timing according to the oil pressure used to drive it. It is driven by oil pressure supplied by the engine oil pump.

VVT-i continuously varies the valve timing within a range of 60 degrees crank angle to achieve the best intake valve timing for operating conditions.

Diagram 3: VVT-i System



5.2 Operation of VVT-i

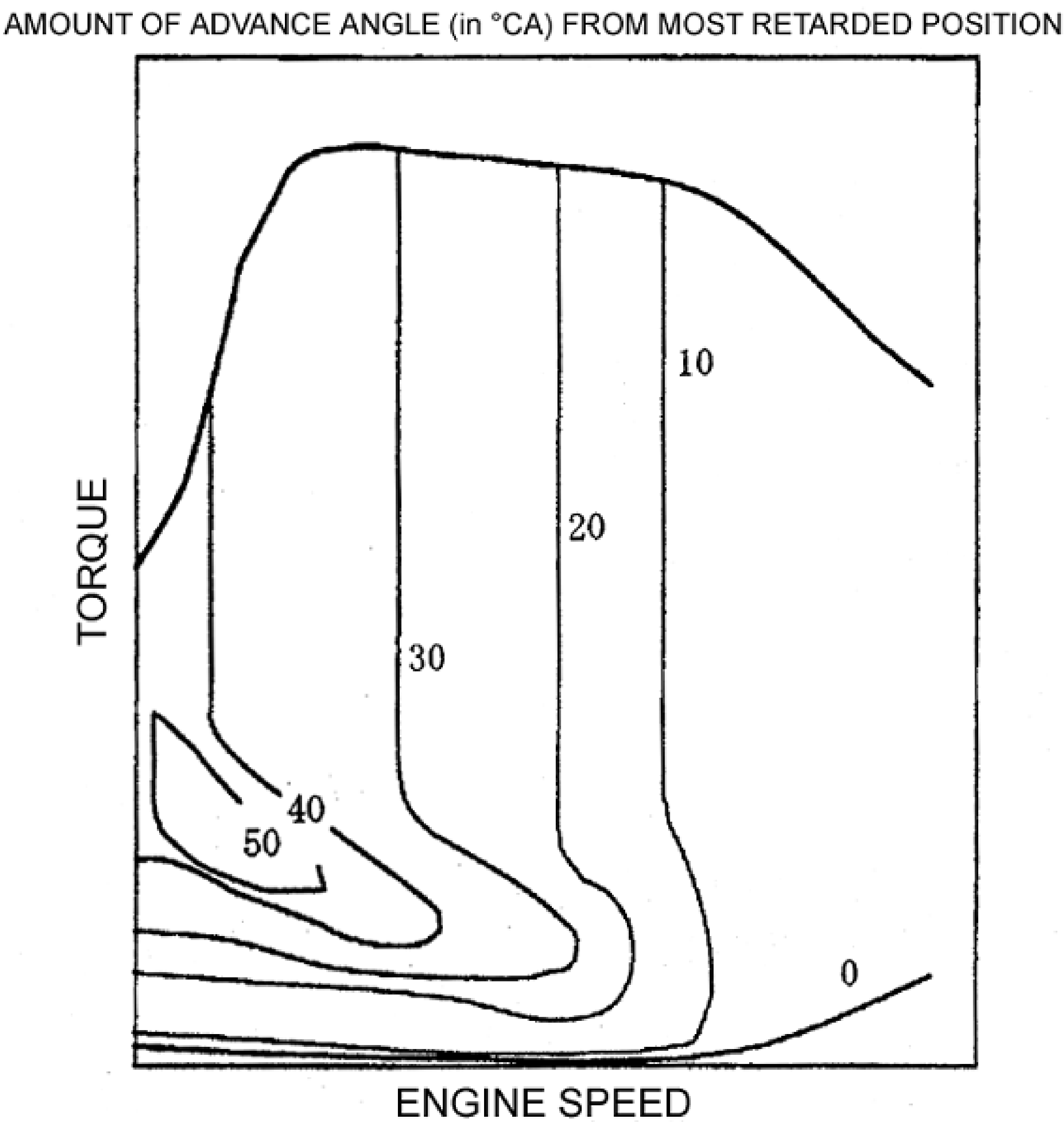
Idling and at light loads The VVT-i pulley angle is retarded, reducing valve overlap, thus stabilizing combustion and reducing vibration at idle.

(1) Operation at partial loads The VVT-i pulley angle is advanced, overlap is increased, increasing internal EGR volume, thus fuel consumption and exhaust emissions are improved.

(2) At high loads At low engine speeds, the VVT-i pulley angle is advanced, resulting in early intake valve closing. At high speeds, the retarding of the cam pulley increases the intake air volume due to the retarding of the intake valve closing.

In this manner, it is possible to provide continuously variable valve timing to satisfy operation requirements.

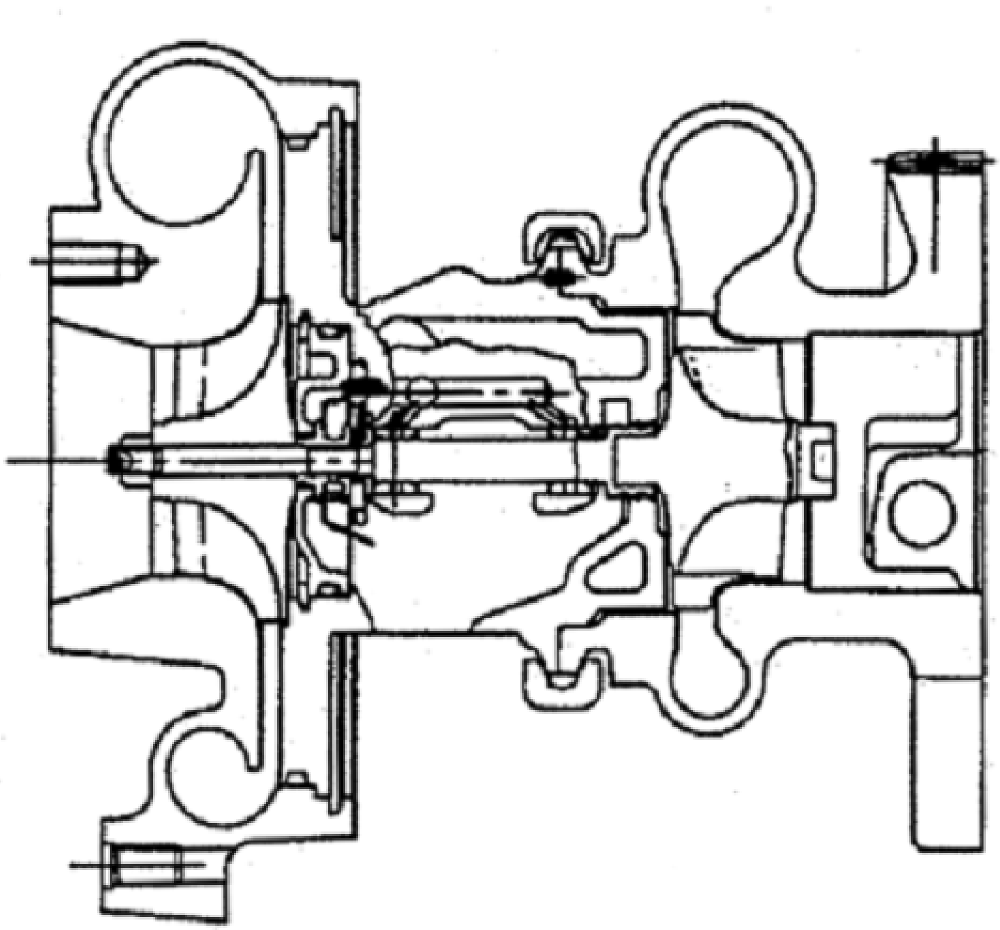
Diagram 4: VVT-i Advance Angle Map



6. CT15B Ceramic Turbocharger

A highly efficient turbocharger, the CT15B, has been developed.
The main specifications are shown in table three, a cross sectional view is shown in diagram 5.

Diagram 5: Turbo Cross-section



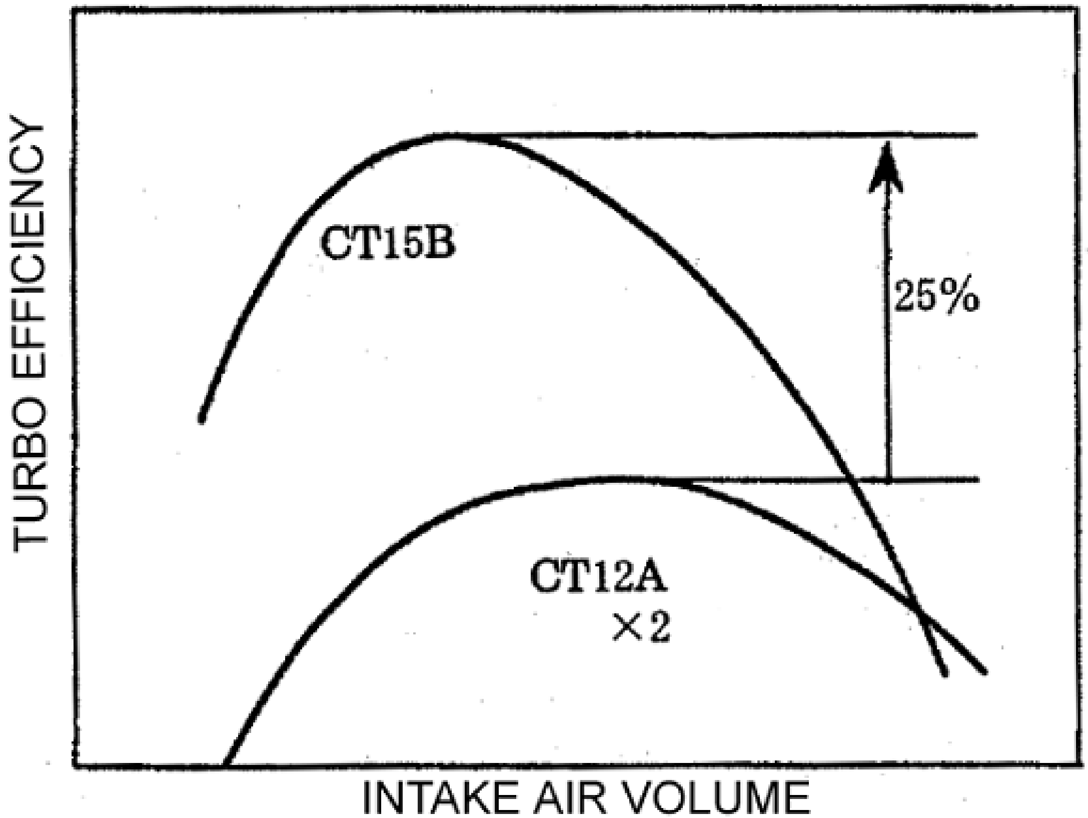
6.1 Turbo Efficiency

In diagram 6, the turbo efficiency is compared with the CT12A twin turbo system of the previous model. Compared to the old model, maximum efficiency has been improved by about 25%.

Primary changes that have resulted in turbo efficiency improvements:

1. Improvement of the shape of the blades of the compressor and turbine wheels
2. Optimization of the size of the compressor and turbine
3. Reduction of tip clearance

Diagram 6: Turbo Efficiency



6.2 Moment of Inertia

The moment of inertia of the rotating part of the turbo has been decreased, improving turbo response.

Primarily:

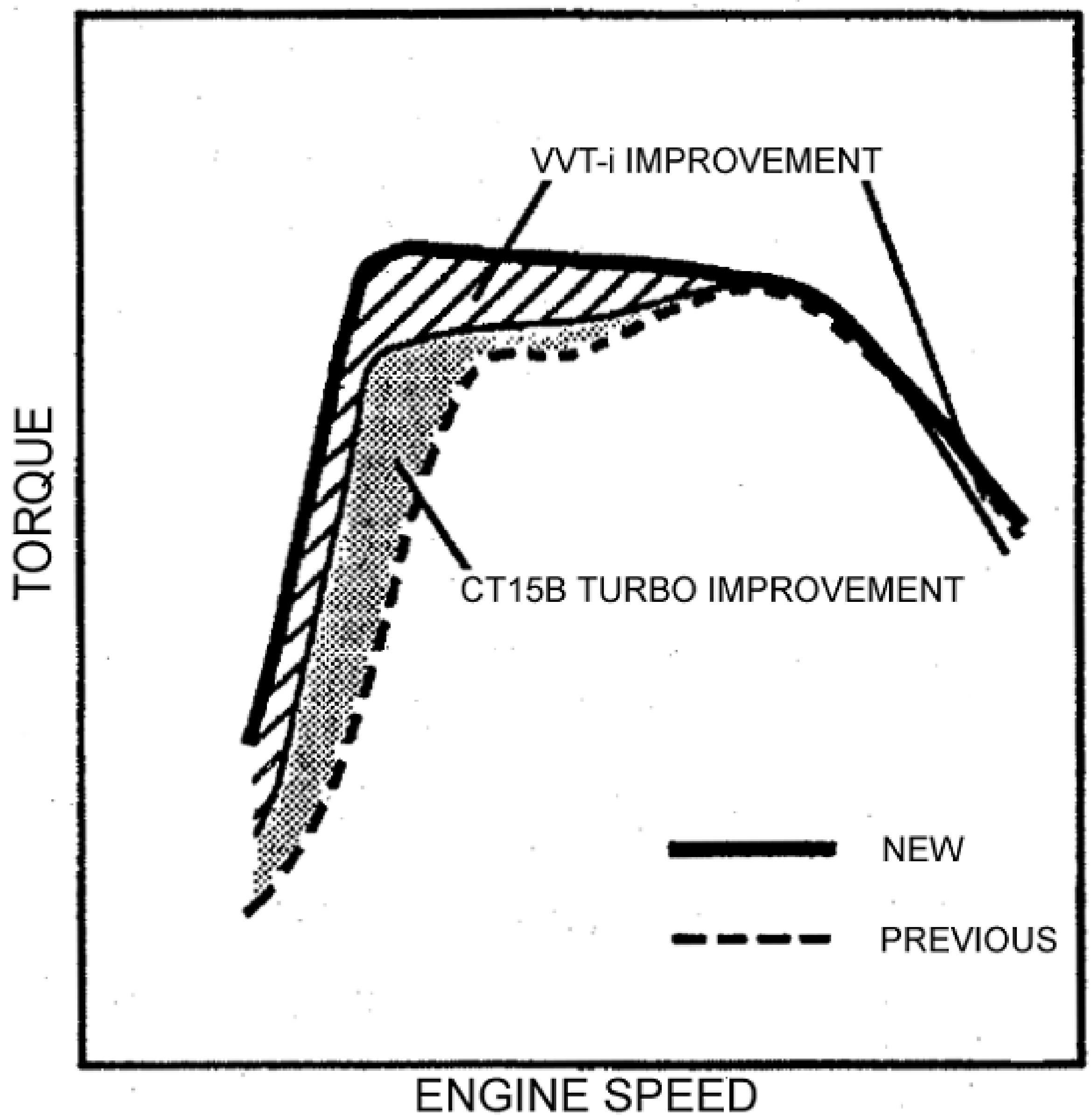
1. Adoption of a ceramic turbine wheel
2. Optimization of the compressor impeller and size of the turbine wheel, blade thickness was reduced, and the weight of parts was reduced.

7. Effects when VVT-i is Combined with a High Efficiency Turbo

7.1 Engine Full Load Efficiency

When VVT-i and this highly efficient turbo are adopted for the existing 1JZ-GTE engine, maximum torque is improved by about 4%, and the torque at 2000 RPM is improved by about 50%.

Diagram 7: Effectiveness of VVT and Turbo (CT15B)



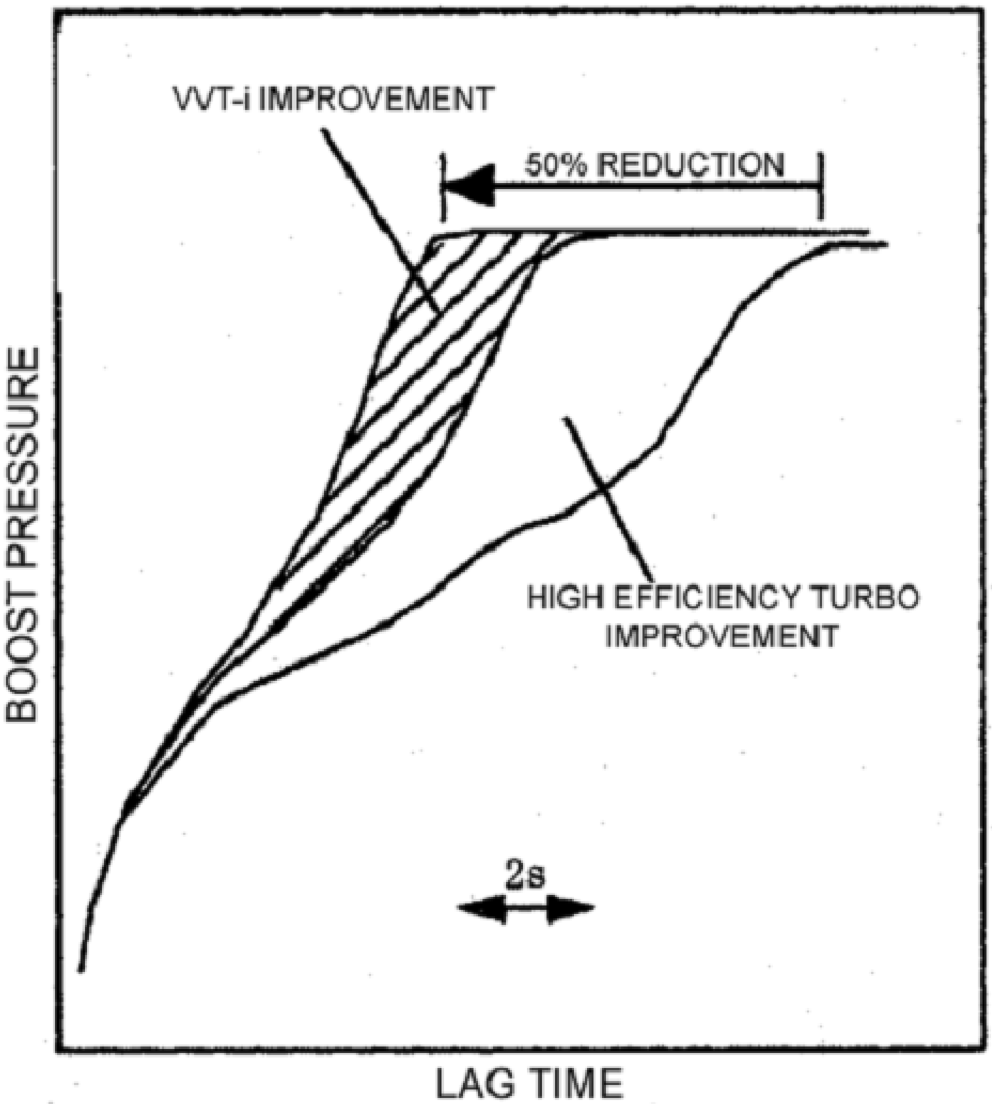
7.2 Turbo Response

Diagram 8 shows the resulting boost when the vehicle is in 4th gear and full acceleration occurs.

Compared with the previous 1JZ-GTE, as a result of adopting VVT-i and the highly efficient turbocharger, the time required to reach maximum boost pressure was reduced by half.

In addition, from low engine speeds, the boost pressure rises in a linear fashion, improving the feeling of acceleration.

Diagram 8: Response in 4th Gear



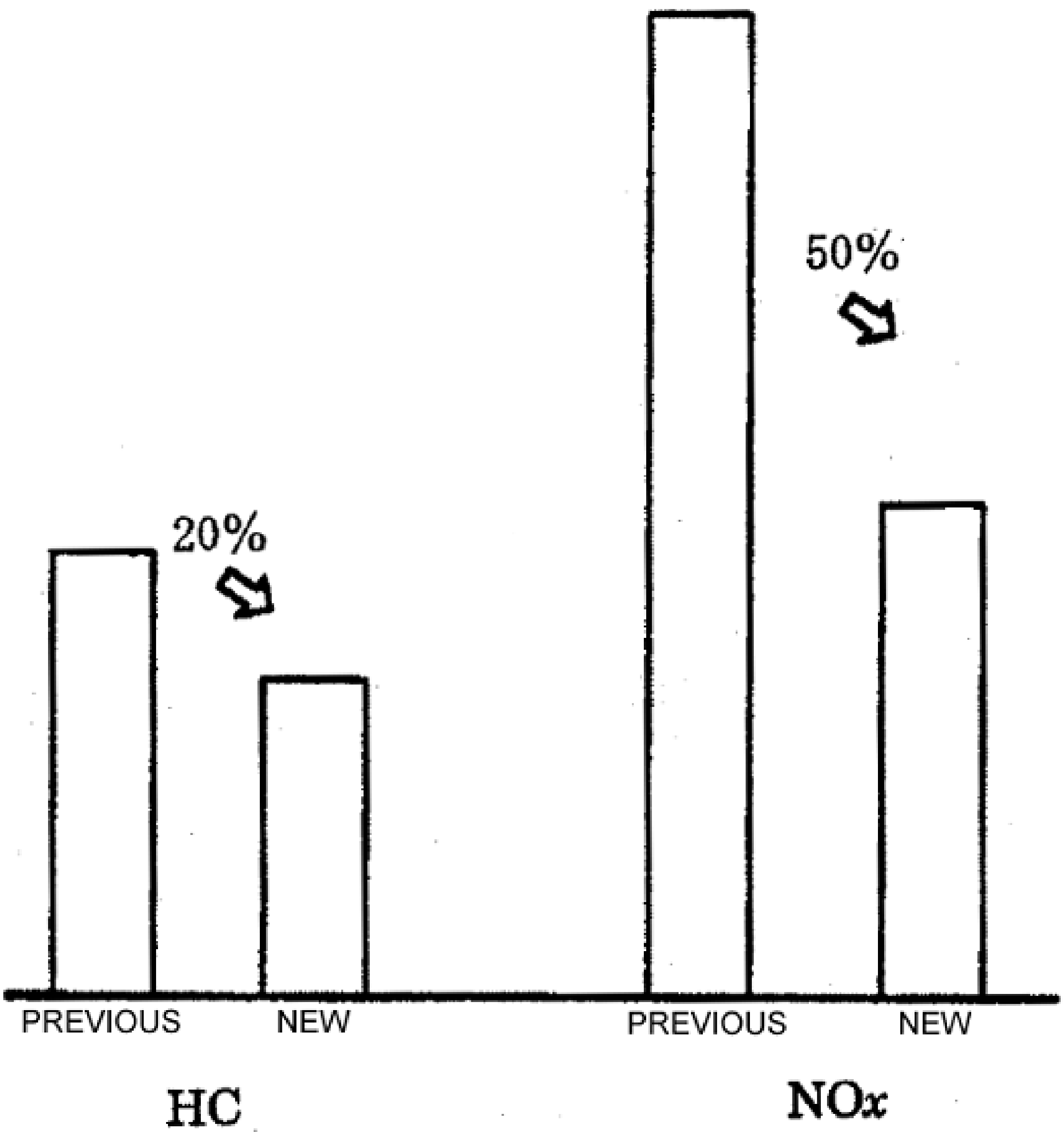
7.3 Fuel Efficiency

The fuel efficiency of the Soarer, measured using the Japanese 10.15 mode test procedure, has improved by about 5% as a result of the use of this engine. In addition, the flex lockup system is used for vehicles with automatic transmissions. For these vehicles, the system allows the lock-up area of the clutch in the torque converter to be increased, resulting in an improvement of about 11%.

7.4 Reduction of Exhaust Emissions

Diagram 9 shows the effects of the HC and NOx reductions, measured in front of the catalysts, using the 10.15 mode. An increase of internal EGR as a result of VVT-i reduces the HC by about 20%, and the NOx by about 50%.
As a result, the catalysts can be made smaller, reducing demands on resources.

Diagram 9: Emissions Improvements

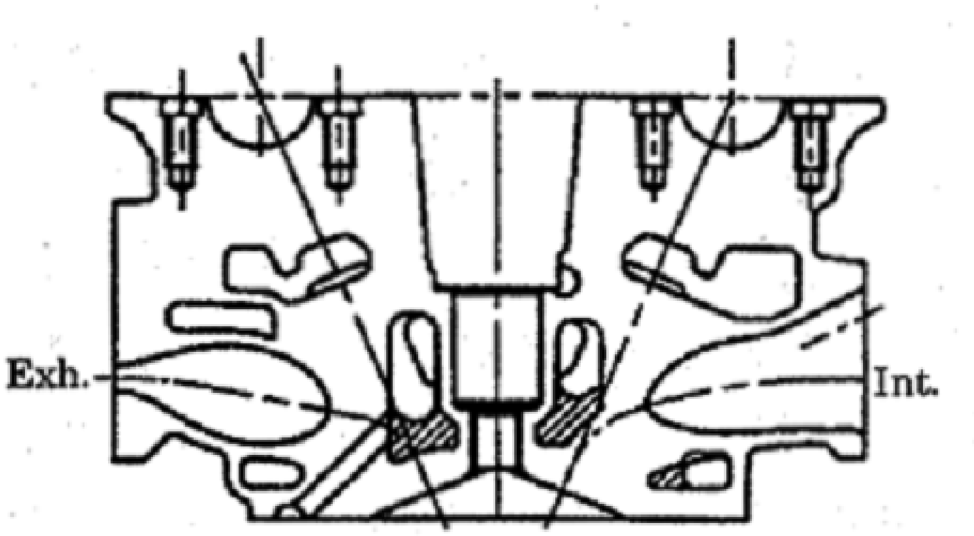


8. Details of Other Improvements

8.1 Increase of Compression Ratio

Due to modification of the water jacket in the cylinder head, cooling performance is improved, improving knock resistance. In addition, the improvement of cooling air flow for the intercooler also helps to allow the compression ratio to be increased from 8.5:1 (previous 1JZ-GTE) to 9.0:1, improving combustion and allowing improved fuel efficiency.

Diagram 10: Water Jacket



8.2 Reduction of Friction

Newly developed shims with a titanium nitride coating as shown in diagram 11 are adopted to reduce friction in the valvetrain. As the surface of the titanium nitride coated shim is finished, the coating is applied, protecting the polished surface of the shim. Simultaneously with the use of the coating, minute projections during the grinding and polishing process decrease the friction drag of the cam and the shim.

The effects of the titanium nitride coating are shown in diagram 12.

In addition, a further improvement was realized via a reduction of the tension of the piston, and the application of a coating to the piston skirts.

Diagram 11: Titanium Nitride Coated Shims

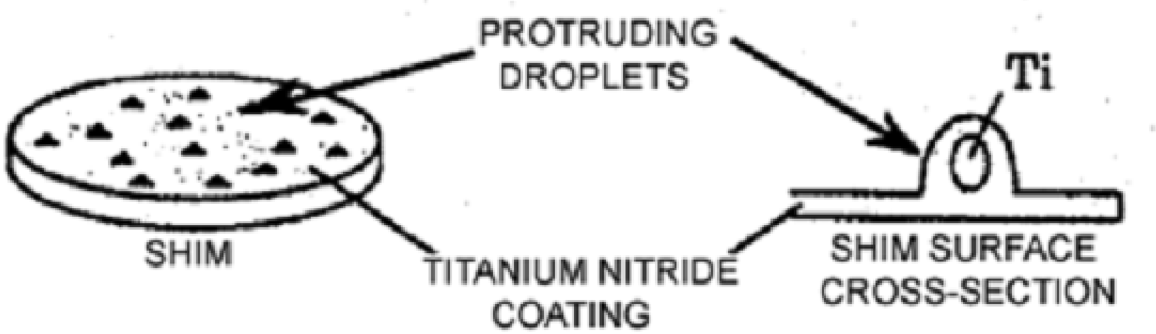
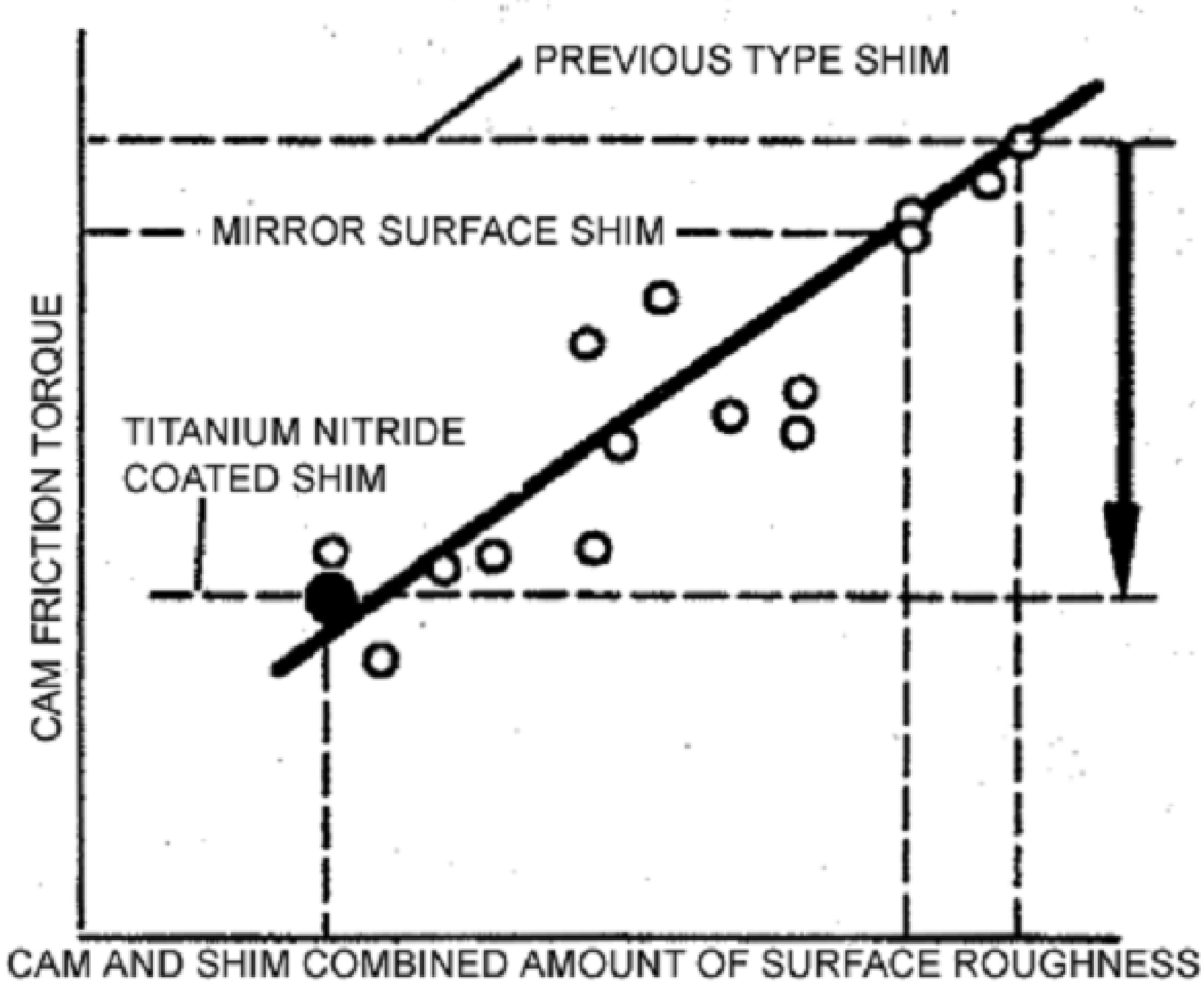


Diagram 12: Valvetrain Surface Roughness and Friction



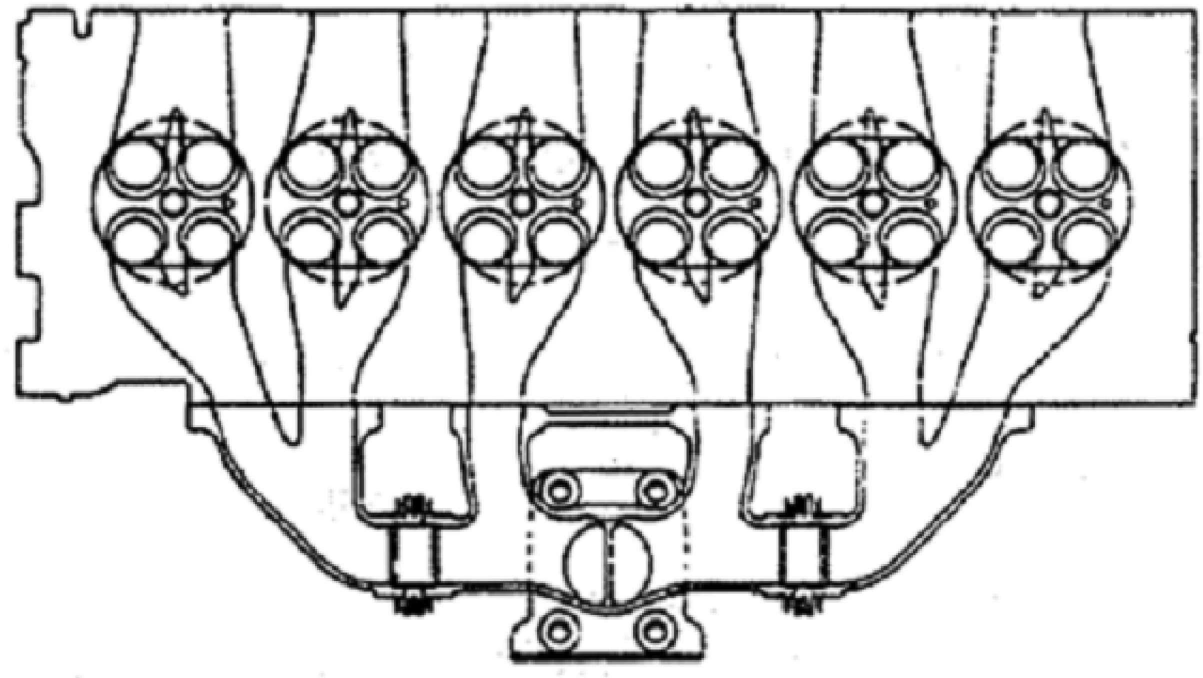
8.3 Electronically Controlled Throttle

A two valve type electronically controlled throttle has been adopted. The opening amount of the throttle valves is controlled according to the accelerator pedal operation and road conditions, achieving safe, smooth accelerator operation.

8.4 Exhaust Flow

The shape of the cylinder head exhaust ports and exhaust manifold are shown in diagram 13. The shape of the exhaust ports, combined with making them smoother increases exhaust flow efficiency. In order to allow for thermal expansion of the exhaust manifold, bellows are placed at either side of the center portion of the exhaust manifold.

Diagram 13: Exhaust Port Shape



9. Summary

The adoption of a continuously variable valve timing system and a high efficiency turbo results in a revolutionary improvement of low and midrange torque and an improvement of turbo response. In addition, it is also possible for good fuel economy and high power to coexist.
The new 1JZ-GTE engine is able to provide just the type of nimble running and good response that a driver is looking for, while still proving economical and having the attributes of a new generation sports engine, assuring customer satisfaction.
To conclude, the great success of the development of this engine was as a result of collaboration both inside and outside the company. To all involved, please accept our profound thanks.

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