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ABSTRACT

The 2ZZ-GE is a sporty 1.8 liter engine based on the 1ZZ-FE, which is currently being mass produced in Japan, USA, and Canada.

It was designed to fit into the same engine compartment as the base 1ZZ-FE, have equivalent vehicle performance as a 2.2 liter engine, and meet TLEV emission standards.

The main features of the 2ZZ-GE are the Metal Matrix Composite (MMC) reinforced all-aluminum cylinder block and the intelligent Variable Valve Timing and Lift (VVTL-i) system. These features were adopted for size and performance.

Other features such as a reinforced ladder frame, and an intake manifold spacer was utilized for a sporty engine sound.

The 2ZZ-GE delivers maximum power at 7600rpm and maximum torque at 6800rpm.

INTRODUCTION

The 1ZZ-FE, base engine to the 2ZZ-GE, was designed with the following targets.

1. To reduce exhaust emissions and improve fuel economy without extra systems. (i.e. direct injection)
2. To make compact and lightweight

The 2ZZ-GE was designed with the following additional targets.

1. Provide high speed performance
2. Retain low speed flexibility
3. Maintain same bore pitch as base engine
4. This was to keep the same outer dimensions
5. Maintain same emission standard as base engine Target TLEV
6. Achieve best power to weight ratio in the field

SPECIFICATIONS

Table 1 shows basic specifications of the 2ZZ-GE engine, in comparison with the base engine, 1ZZ-FE.

Figure 1 shows the outline of the 2ZZ-GE compared to the 1ZZ-FE. The basic outer dimensions were kept equal while performance was increased.

Table 1. Basic Specifications

	2ZZ-GE	1ZZ-FE
Displacement (cc)	1795	1794
Bore x Stroke (mm)	82 x 85	79 x 91.5
Compression	11.5	10
Valve Train	DOHC 4 Chain Driven VVTL-i	DOHC 4 Chain Driven VVT-i
Aspiration	natural	natural
Cylinder Block	Aluminum w/MMC liner	Aluminum w/Cast iron liner
Bore Pitch (mm)	87.5	87.5
Bore wall (mm)	5.5	8.5
Valve Dia. (mm)	Int 34 Exh 29	Int 32 Exh 27.5
Max Power	135kw/7600rpm	107kw/6400rpm
Max Torque	180Nm/6800rpm	172Nm/4400rpm
Size (LxWxH) (mm)	652 x 608 x 659	639 x 586 x 632
Dry weight	115kg	102kg

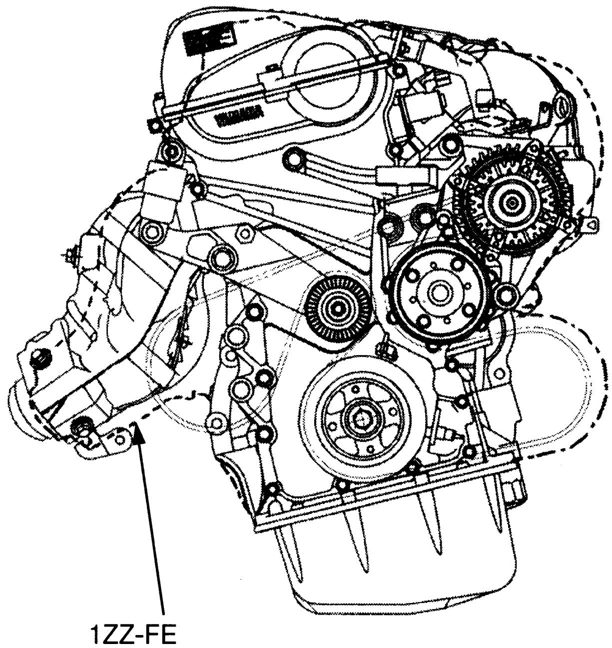

Figure 1. Engine Outline

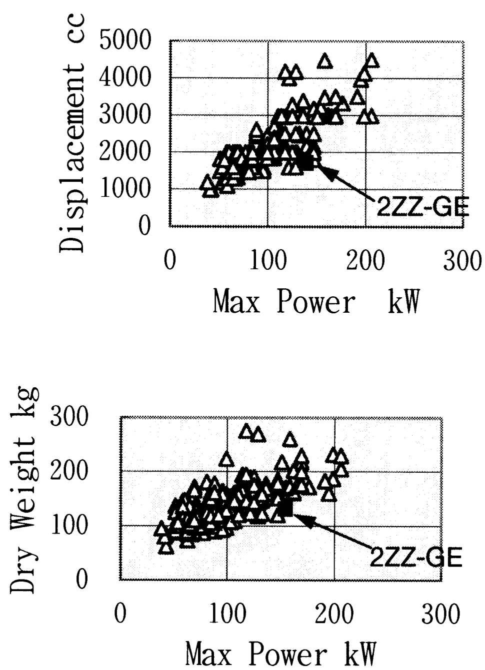

Figure 2. Power to Weight and Power to Displacement Comparisons

Figure 2 shows the Power, weight, and displacement of the engines in the Japanese market. 2ZZ-GE is among the top of all engines.

The MMC all-aluminum cylinder block with a minimum bore to bore wall thickness of 5.5mm made this compactness and low weight possible. The aluminum alloy cylinder bore has been reinforced with ceramic fibers and particles, a combination which we found most favorable amongst thermal spraying, plating, and a cast-wrapped aluminum liner.

Table 2. Comparison of Aluminum Blocks

	Linerless			Cast-wrapped liner	
	MMC	Thermal spray	Plating	Aluminu m	Cast iron
Bore temp.	B	B	B	B	D
Bore rigidity	A	B	B	C	C
Bore strength	A	B	B	C	C
Head Gkt seal	A	B	B	B	B

A; excellent B; very good C; good D; poor

The details of the MMC cylinder block will be introduced in a separate paper.

HIGH SPEED PERFORMANCE AND LOW SPEED TORQUE

The 2ZZ-GE adopted a Variable Valve Timing and Lift system called VVTL-i. The system changes valve timing over the entire speed range in accordance to engine speed and load. This feature is also used in the base engine. VVTLi also changes valve lift and event angles at 6000rpm from low to high. Table 2 shows the changes in valve timing and lift.

Table 2. Valve Timing and Lift

	Exhaust			Intake		
	Open BBDC (CA)	Close ATDC (CA)	Lift (mm)	Open BTDC (CA)	Close ABDC (CA)	Lift (mm)
Low	34	14	7.6	-10 to 33	58 to 15	7.6
High	56	40	10.0	15 to 58	97 to 54	11.2

VVTi mechanism allows the valve timing of the intake cam to be changed continuously in the range shown.

VVTL-i MECHANISM – The valve timing change mechanism of the VVTL-i system, VVT-i, has already been introduced in other papers.

Figure 3 shows the schematic drawing of the lift change mechanism of the VVTL-i. Figure 4 shows the detail of the mechanism set inside the rocker arm.

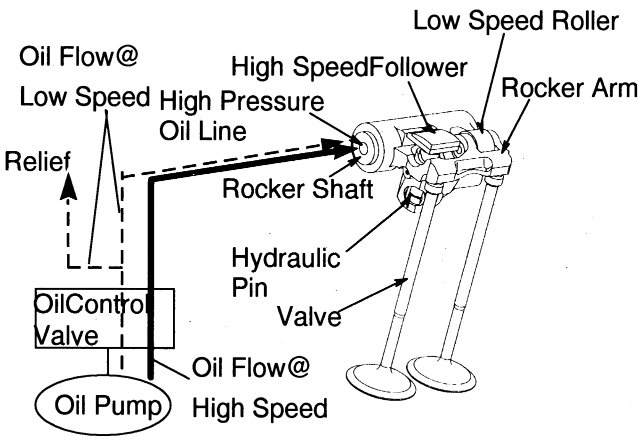

Figure 3. Lift Change Schematic

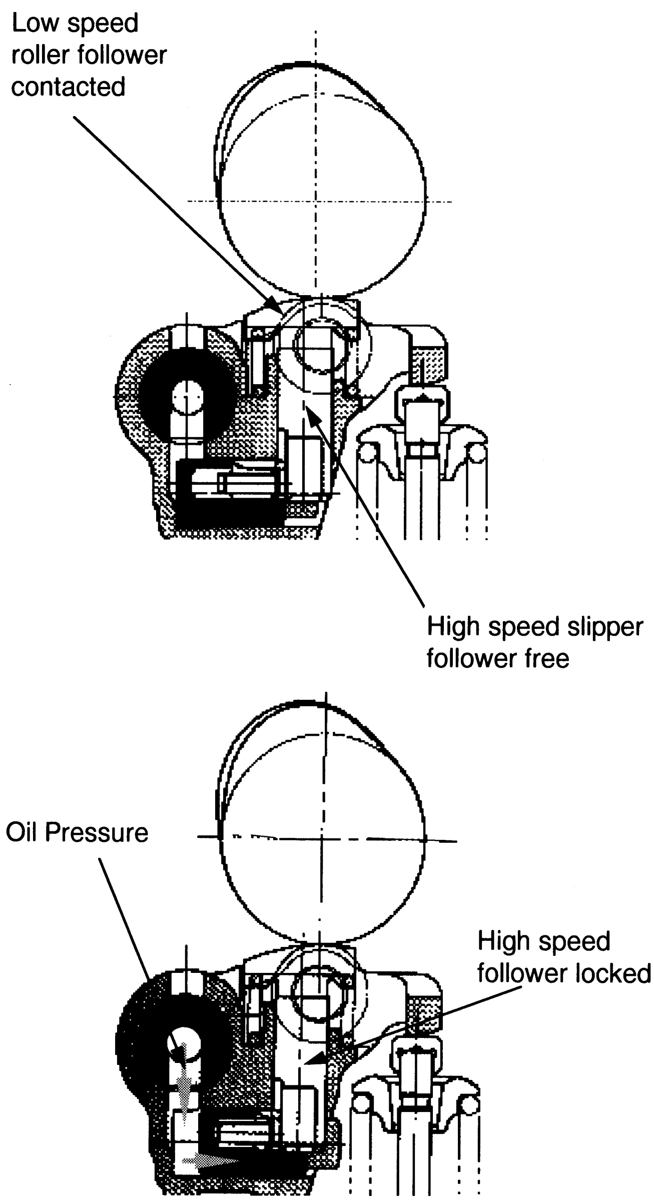

Figure 4. Detail of Mechanism

At engine speeds below 6000rpm, the rocker arm moves according to the low lift roller follower. When engine speed is above 6000rpm, hydraulic pressure is applied to the locking pin, which slides under and locks the high lift slipper follower to the rocker arm. This creates the difference in valve lift, for the rocker arm will now move according to the high lift slipper. When engine speed is below 6000rpm, the return spring pushes the locking pin back, and the high lift slipper is freed.

<u>Choice of Follower</u> – A few considerations were made when choosing a follower which best suited the 2ZZ-GE.

1. To provide high speed performance
2. To have low speed flexibility

These requirements came from the original targets.

Volumetric Efficiency – Angle-lift area of the cam angle to lift curves has a large effect on the volumetric efficiency of an engine. The volumetric efficiency has a large effect on engine maximum performance.

Figure 5 compares angle-lift areas of slipper, direct drive, and roller followers. Throughout the speed range, a slipper shows the largest angle-lift area.

We therefore decided that a rocker arm with a slipper follower would be the best choice to gain high speed performance.

Friction – At low engine speeds, valve train friction accounts for 30% of the total friction of an engine and therefore has a large effect on low speed flexibility of an engine.

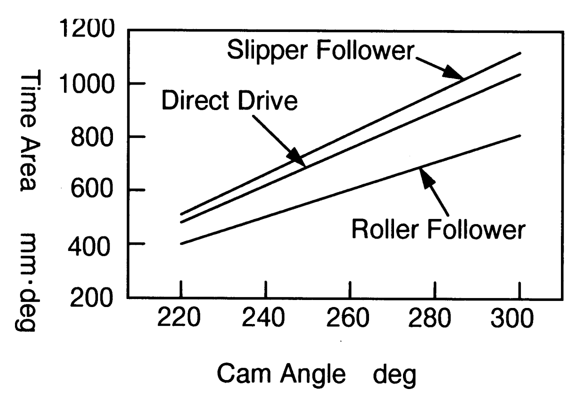

Figure 5. Angle Lift Area

Figure 6 shows friction for slipper, direct drive, and roller followers. Roller shows lowest friction, but at high engine speeds, the difference between followers is substantially smaller.

We therefore decided a rocker arm with a roller follower to be the best choice for low speed flexibility.

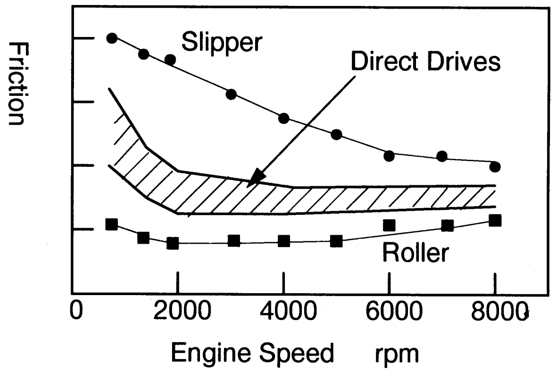

Figure 6. Friction

For the base engine, direct drive mechanism was adopted as the best single choice, but for the 2ZZ-GE, we chose the roller follower for the low speed cam and slipper follower for the high speed cam.

This means two different followers will be set onto one rocker arm.

Technical Problems with Two Different Followers

Material Selection – The roller will be made of hardened steel and the slipper from ferrous sintered metal. For the cam material, ferrous sintered metal was chosen for pitting and scuffing durability.

The cam is brazed to the shaft and sintered simultaneously. Then, two different surface finishes were applied separately to the high and low lift cams.

Special care was taken to control the initial wear of the high speed cam.

Lubrication – Slipper type follower needs to be lubricated for anti-scuff characteristics so shower lines were added to the head cover.

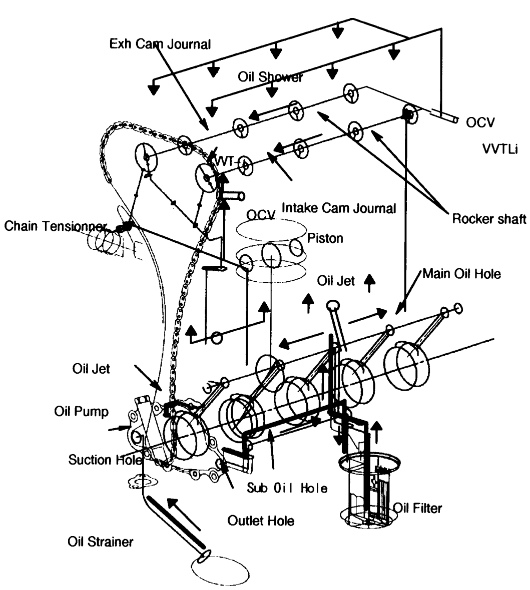

Figure 7. Lubrication System

Figure 7 shows the lubrication system of the 2ZZ-GE.

The hydraulic pressure line which passes through the rocker shaft also lubricates the rocker arms. Oil is fed through this line at all speeds, and at high speeds the oil control valve (OCV) allows additional oil to flow into the pressure line to lock the high speed follower.

Movement of Valve and Spring – Figure 8 shows the actual valve lift curves, before and after improvement of rocker arm rigidity and mass.

Inset shows detail of lift curves at high and low speeds.

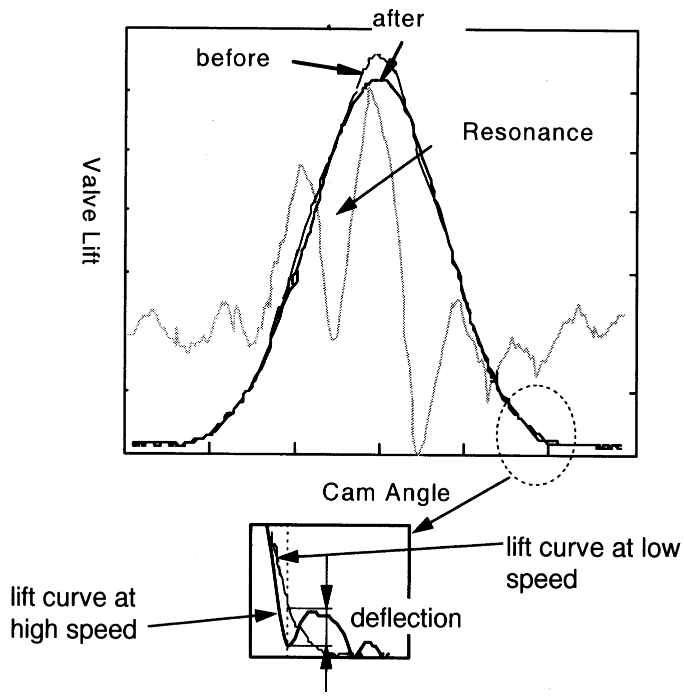

Figure 8. Actual Lift Curves

The original showed a resonance during lift, and a large deflection at valve closing. Resonance affects the reliability of the valve spring, and deflection affects the performance of the engine.

Valve lift acceleration was changed to improve resonance, and rocker arm rigidity was increased to improve deflection.

Lock Pin Durability – The lock pin does not slide under the high speed follower within 1 camshaft revolution. When the overlap of the lock pin and follower is still small, the pin can get kicked back. This will cause a slight wear of the corners of lock pin and follower, increasing the chances for the kick back to occur. When the average of the wears of the lock pin and follower exceeds a given value, the lock pin will always be kicked back, and the valve lift will not switch to high.

We decided the criteria number of low-high cycles based on an actual circuit run, and controlled the wear to an acceptable level. Two main methods were used to control the wear.

- Balancing the wear
    1. The same material and surface finish used for both lock pin and follower
    2. Optimization of corner shapes
- Increasing velocity of lock pin
    1. Increasing available hydraulic pressure
    2. Decreasing lock pin weight

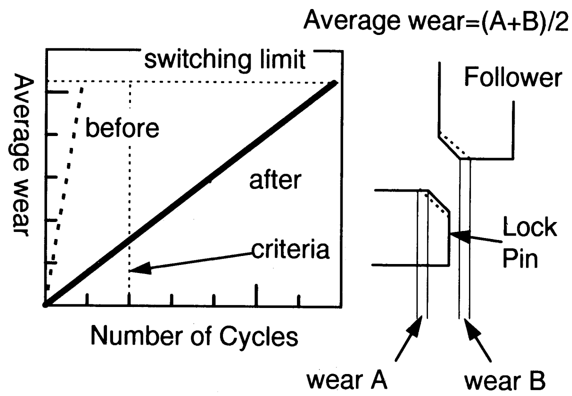

Figure 9. Lock Pin Wear

EFFECT OF VVTL-i – Figure 10 shows the torque curve of the 2ZZ-GE. The torque increase from variable valve timing is approximately 5% below 6000rpm and 2% above 6000rpm. At above 6000rpm, the variable valve lift shows a big torque increase of 22%.

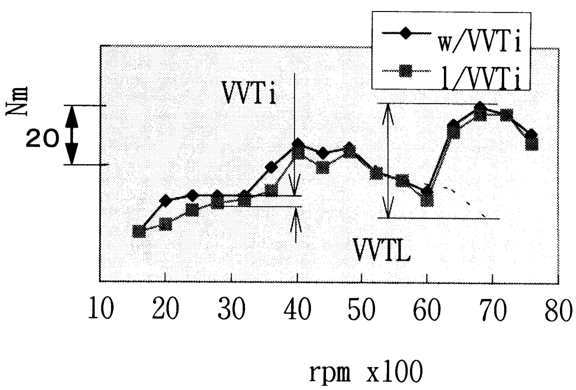

Figure 10. Torque Curve

OTHER FEATURES FOR HIGH SPEED OPERATION

Oil Pan – Figure 11 shows oil pan and baffle plate set on the ladder frame. The oil pan itself is without a baffle. This quickens the return of oil into the oil pan, increasing performance. Air suction was minimized by optimally positioning the suction pipe inlet. The 2ZZ-GE can withstand 1.0G without sucking air.

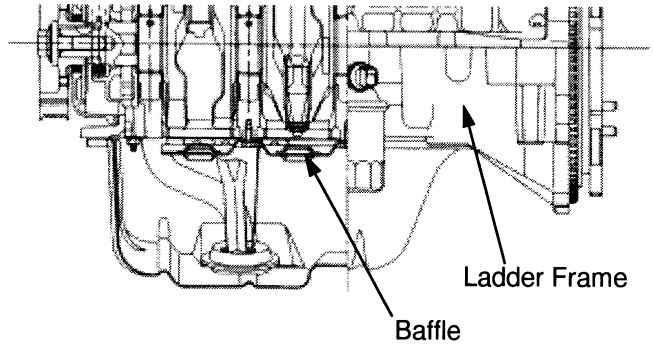

Figure 11. Oil Pan

Crankshaft and Connecting Rod – Table 3 compares the crankshaft dimensions with the base engine. The pin journal diameter was enlarged by 1mm and the stroke was shortened by 6.5mm.

Table 3. Crankshaft Dimensions (mm)

	2ZZ-GE	1ZZ-FE
Main Journal Diameter	48	48
Pin Journal Diameter	45	44
Journal Overlap	4	0.25

As for bearings, the connecting rod uses Kelmet material, the main is aluminum.

Intake Manifold – Figure 12 shows the intake manifold.

A large surge tank (4.5 liters) and intake manifold runners made from aluminum pipes were adopted.

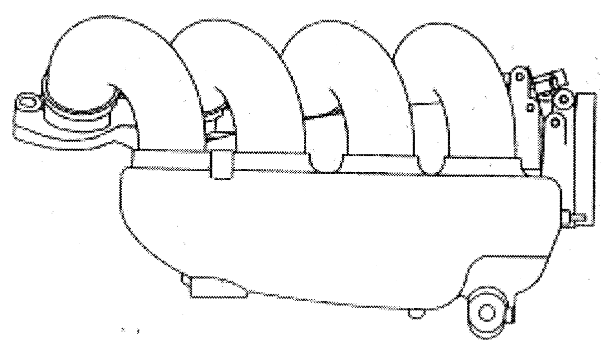

Figure 12. Intake Manifold

Compression Ratio – A high compression ratio of 11.5 was adopted. It was made possible by the adoption of an all-aluminum cylinder block.

EXHAUST EMISSIONS

THETA EXHAUST PIPES – Figure 13 shows the exhaust manifold.

In order to maintain high speed performance while keeping heat loss from the exhaust pipes to a minimum, a cylindrical pipe with a partition wall (theta pipe) was adopted.

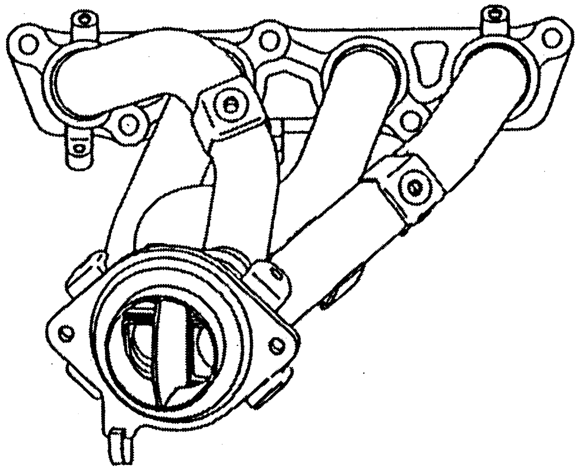

Figure 13. Exhaust Manifold

Emissions and Power – Figure 14 shows catalyst heat-up of dual exhaust pipes and theta pipe.Theta pipe shows quicker heat-up.

In order to meet TLEV standards, the theta pipe without other systems was selected.

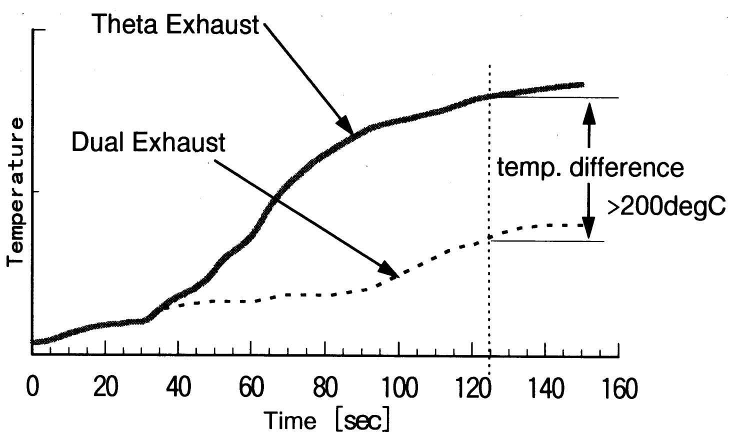

Figure 14. Catalyst Heat-up

Power to Aperture – Figure 15 shows the effect of aperture size between exhaust manifold and front pipe on maximum power. The larger the aperture, the lower the power. The aperture was set to the present level as a compromise between power, manufacturability, and design clearance (heat, vibration, etc).

Maximum power for dual pipe will be at aperture =0.

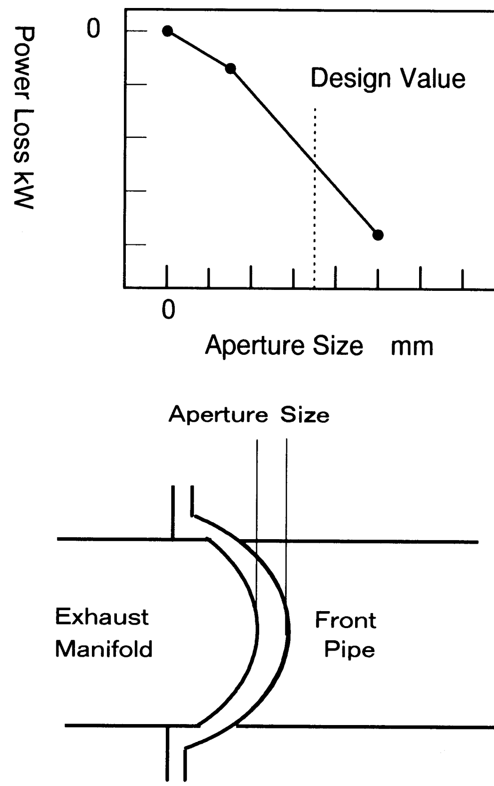

Figure 15. Aperture Size and Power Difference

FUEL ECONOMY

Figure 16 compares maximum power and fuel economy (City and Highway) for engines in the US market. When compared in terms of maximum power, the 2ZZ-GE shows high City fuel economy and is one of the best for Highway fuel economy.

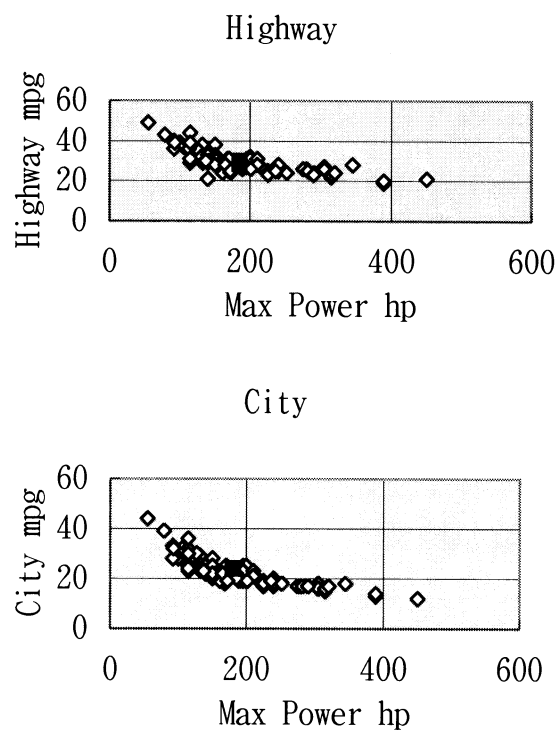

Figure 16. Max Power vs Fuel Economy

ENGINE SOUND

Since 2ZZ-GE is an engine with a high revolution limit, a low final gear ratio of 4.529 was chosen for the manual transmission. Noise suppressing insulation could not be added to the inside of the engine hood, because the hood line was low. Acoustic intensity was measured and a rubber spacer was added between the intake manifold and the block . This filled a volume which was acting as a resonance chamber.

Figure 17 shows the acoustic intensity measurement result.

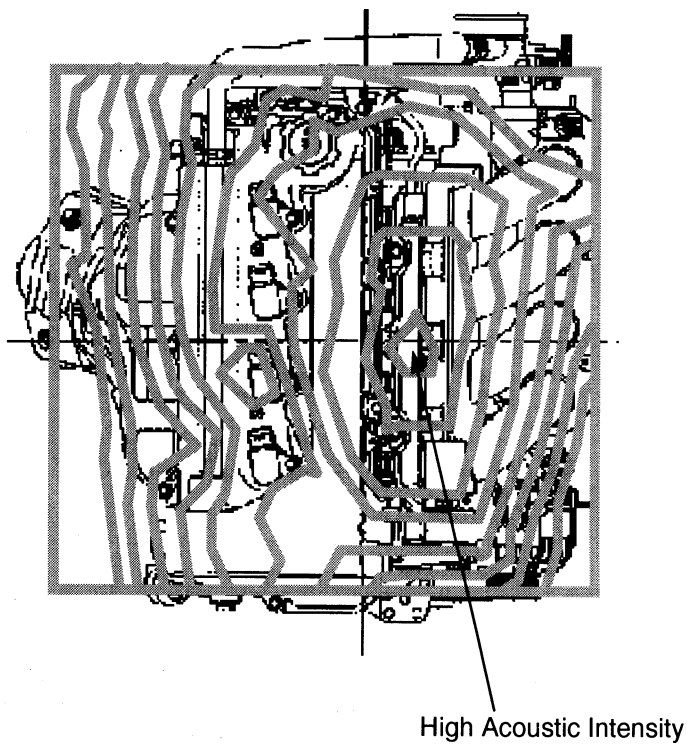

Figure 17. Acoustic Intensity

Improvements were also made to the head cover, timing chain cover, and transmission hole cover using this method.

CONCLUSION

1. A sporty, compact, lightweight, high power, and flexible engine was developed
2. An MMC all-aluminum cylinder block with bore wall thickness of 5.5mm was developed. This contributed to its compactness and low weight.
3. The VVTL-i system, which switches valve lift between low and high, and controls valve timing at the same time, was developed. This contributed to the 2ZZ-GE's high power and flexibility.

ACKNOWLEDGMENTS

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