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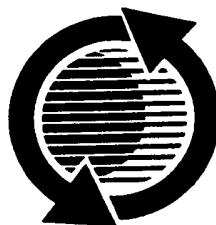
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A New 4.5 Liter In-Line 6 Cylinder Engine, 1FZ-FE for the Toyota Land Cruiser

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ABSTRACT

A new 4.5 liter in-line 6 cylinder engine, 1FZ-FE has been developed for the Toyota Land Cruiser.

To obtain high power, fuel efficient engine, we adopted the most advanced Toyota technologies, such as Toyota original 4 Valve DOHC system with scissors gear between camshafts, compact combustion chamber with smooth inlet and outlet system, KCS and so on. The engine produces 212 HP at 4600 rpm and 275 ft-lbs at 3200 rpm.

Aluminum cylinder head, short skirt cylinder block stiffened with aluminum oil pan give the engine light weight and make it rigid enough to have low vibration and quietness.

And we also designed every engine part appropriately so as to make the engine durable enough in severe operating condition of off-road vehicle.

1. Remarkable enhancement of engine performance for 'fun to drive' vehicle. The engine hence must be capable of generating affluent torque even at low speeds, in order to ensure comfortable running with a sufficient margin of performance even on off-roads.

2. Emission and fuel economy requirements must be met in a compatible manner at a high level of attainment

3. Tough reliability must be so provided that the engine can endure severe operating conditions of four-wheel drive (4WD) vehicle.

The development has been proceeded based on such major concepts, aimed at developing an engine that can be used continuously even in the 21st century.

MAIN SPECIFICATIONS

DESIGN CONCEPT

The authors, et al. proceeded with the development of the engine more suitable for the Toyota Land Cruiser (than the conventional 3F-E engine) with particular attention paid to following points, while maintaining desirable features of the 3F-E engine.

Main specifications of the developed 1FZ-FE engine are shown in Table 1, while the longitudinal section is shown in Fig.1 and the cross section is shown in Fig.2.

The 1FZ-FE engine has a four-valve DOHC type cylinder head, six cylinders with the bore of 100mm, and the total displacement of 4,477 cc.

Fig. 3 shows the comparison of engine performance between the 1FZ-FE engine and 3F-E engine measured by bench tests.

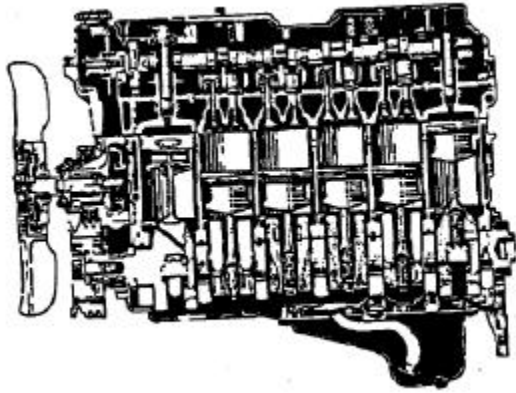


Fig. 1 Longitudinal Section

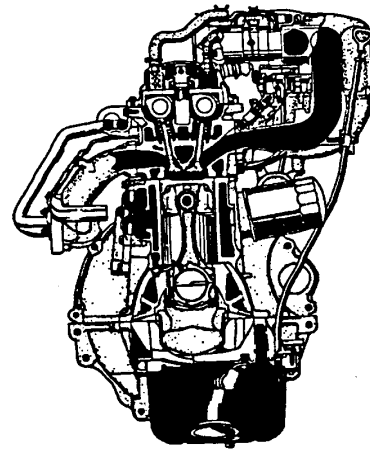


Fig.2 Cross Section

Table 1 Main Specification

Engine	1FZ-FE	3F-E
Type	Water-cooled Gasoline	Water-cooled Gasoline
No of Cyls. & Arrangement	6-cylinder, in-line	6-cylinder, in-line
Valve Mechanism	4-valve, DOHC, Chain & Gear Drive	2-valve, OHV, Gear Drive
Manifold	Cross-flow	Counter-flow
Displacement	4,477 cc	3,956 cc
Bore x Stroke	100 x 95 mm	94 x 95 mm
Compression ratio	9.0 : 1	8.1 : 1
MAX. Output SAE-NET	158 kW (212 HP @ 4600rpm)	115 kW (155 HP @ 4000 rpm)
MAX. Torque SAE-NET	373 kW (275 ft-lbs @ 3200rpm)	299 Nm (220ft-lbs @ 3000 rpm)
Length x Width x Height	940 x 670 x 825 mm	960 x 595 x 815 mm
Weight	265 kg	260 kg

FEATURES OF 1 FZ-FE ENGINE

The 1 FZ-FE engine has collective essence of most advanced technologies of Toyota described below, for the attainment of high performance and low specific fuel consumption, and ensuring low vibration, low noise and high reliability for Toyota Land Cruiser of '93 model year. The technologies used in the engine are shown in Table 2.

Table 2 Features of 1 FZ-FE Engine

High Performance;

- >4-Valve DOHC
- >Knock Control System(KCS)
- >Pentroof type combustion chamber
- >Vertical narrow intake port

Light Weight and Compact Design;

- >Compact DOHC (w/scissors gear mechanism.)
- >Aluminum oil pan and cylinder head
- >Single roller chain

Low Noise and Vibration;

- >High rigid cylinder block with curved rear section (funnel shape)
- >12 balance steel crankshaft
- >Aluminum oil pan

Low specific fuel Consumption;

- >High compression ratio
- >Vertical narrow intake port
- >Sequential fuel injection
- >Lower friction of moving parts

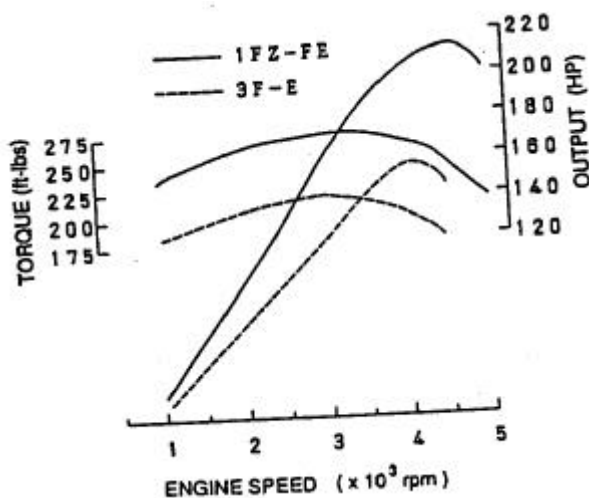


Fig.3 Performance Curve

High Reliability;

- >Oil jet for piston cooling
- >Oil cooler incorporated in cylinder block
- >Drilled coolant passage between cylinder bores
- >Full-float type piston with resin (plastic) coated skirt

COMPACT DESIGN

Because of the introduction of the new engine which did not coincide with the vehicle model change, the basic physical dimension was made the same as that of conventional 3F-E engine, and the development was conducted taking account of more stringent exhaust emission standards in future, CAFE, etc.

The 1FZ-FE engine aimed at a drastic enhancement of engine performance, despite the fact that the physical dimension (LengthX WidthX height) remained roughly the same as that of 3F-E engine.

Namely, the new engine developed under such restrictions has attained 13 % increase of displacement (total displacement; 4,477cc) over the 3F-E engine while maintaining a roughly equal physical dimension. The increase in the engine weight, on the other hand, remained to very low level (+5kg) considering its engine performance increase.

COMPACT CYLINDER HEAD

The aluminum cylinder head has cross-flow type port system, under which the intake cam drives the exhaust cam through a scissors gear with the narrow valve angle of $18^{\circ}29'$ to realize a compact combustion chamber.

The attainment of power increase by the effect of intake inertia with efficient combustion is realized by adopting a wide squish area and the narrow vertical intake port.

The weight reduction of 10kg or so is also attained by replacing the cylinder head material from cast iron (for 3F-E engine) to aluminum (for 1FZ-FE engine). The strength and the reliability of head bolts are ensured by using tightening in the plastic region method.

IMPROVEMENT COMBUSTION EFFICIENCY

The effect of the vertical narrow intake port on the combustion efficiency is shown in Fig.5.

Owing to the shape of the vertical narrow intake port just before the intake valve, the tumble intensity

varies markedly and shows the reverse tendency to that of the intake air flow rate.

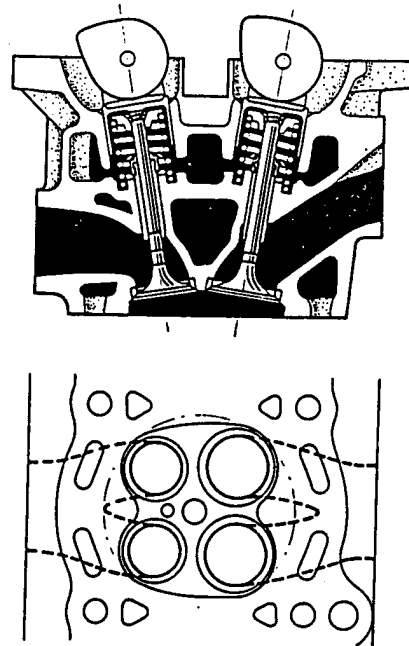


Fig.4 Cylinder Head

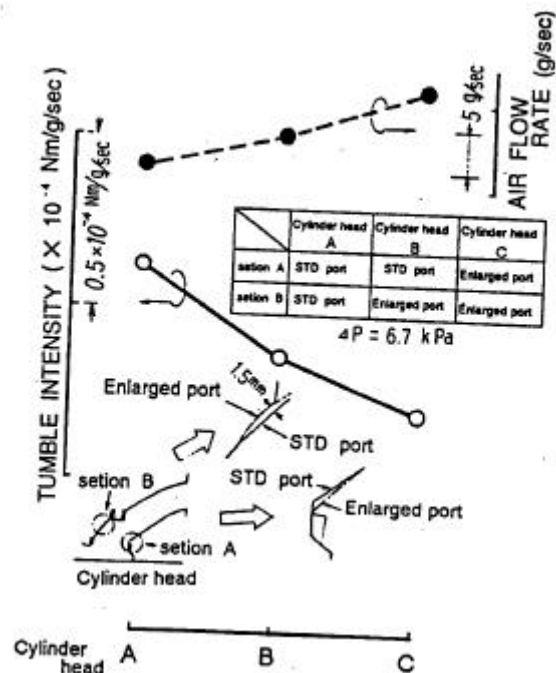


Fig.5 Tumble Intensity

The EGR limit (EGR ratio at which the torque fluctuation constitutes the limit of vehicle surging) characteristics due to the difference in the geometry of intake port is determined as shown in Fig.6. The EGR limit of B head is improved by 4% over the C

head is selected for the new engine.

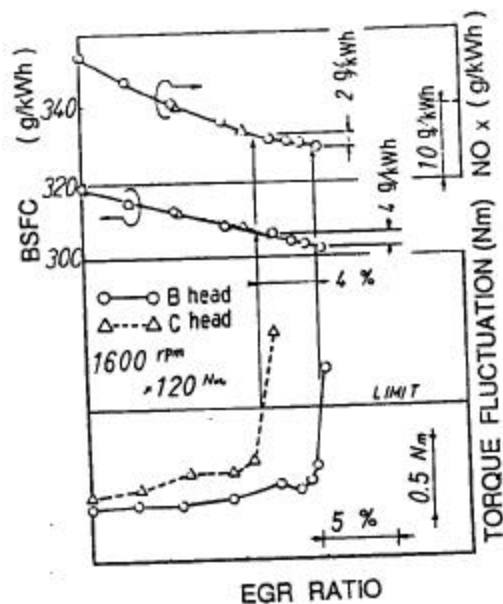


Fig.6 Characteristic of EGR Limit

PISTON

Strutless piston made of aluminum alloy is used in this engine. The skirt profile is determined so as to have appropriate contact pressure distribution through CAE method (1).

Fig.7 shows the outer shape of piston, while Fig.8 shows the results of contact pressure distribution analysis.

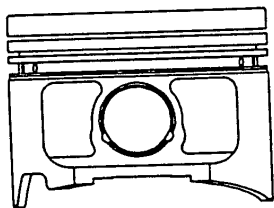


Fig.7 Piston

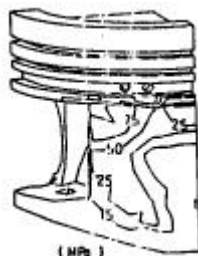


Fig.8 Simulation Result

The oil jet is injected through the oil jet hole at the thrust side of each piston located on the lower deck of cylinder block, in order to cool the piston and to enhance the reliability. The effect of oil jet is

shown in Fig.9.

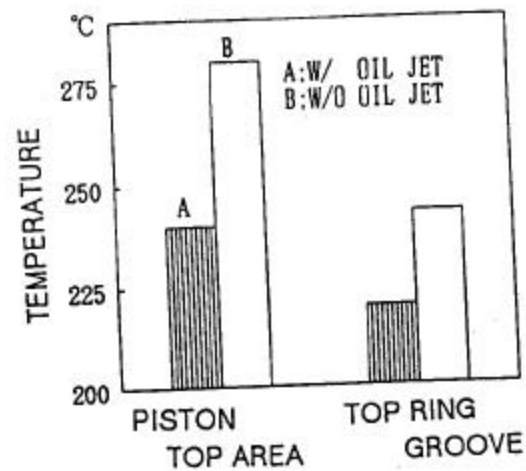


Fig.9 Effect of Oil Jet

CYLINDER BLOCK

A cylinder block is made of cast iron, with a short skirt and the funnel shaped rear end. The rigidity of block is increased by curving the outer wall surface and the optimization of the rib structure.

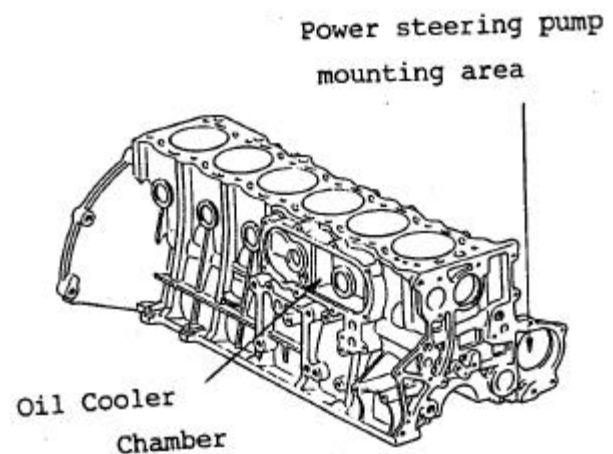


Fig.10 Cylinder Block

Fig. 10 shows the cylinder block. The oil cooler is incorporated in the right-hand wall of the block, while the gear-driven type power steering pump is installed directly to the front end on the left side, by which a number of parts including the V-belt are eliminated.

LUBRICATION SYSTEM

Fig. 11 shows the lubrication system. The gear-driven type oil pump by the crankshaft is employed here. The sufficient amount of oil (total 8 liters) is ensured.

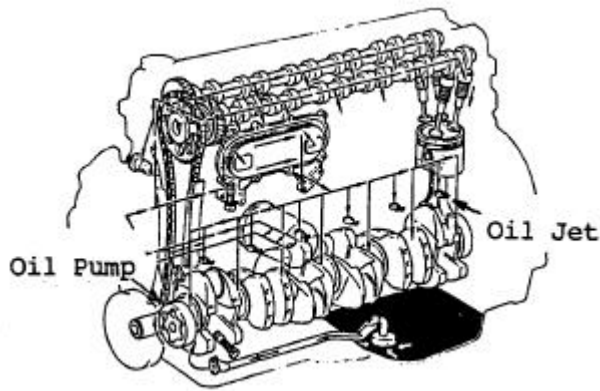


Fig. 11 Lubrication System

OIL PAN

Upper and lower two-layer type oil pans are adopted, with upper oil pan made of aluminum die cast and lower oil pan made of rust-resistant sheet steel.

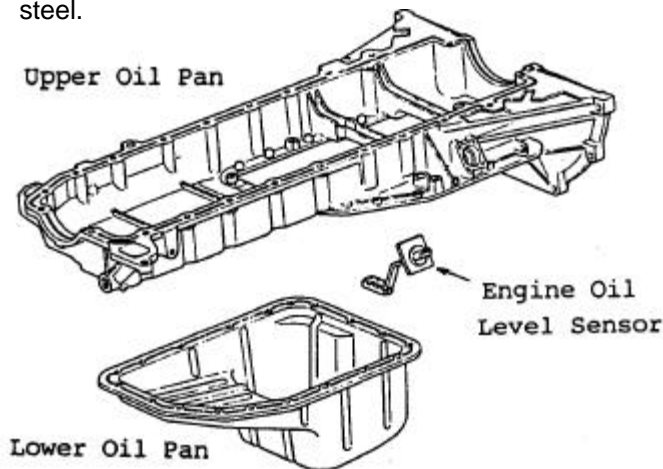


Fig. 12 Oil Pan

The aluminum die cast is used for upper oil pan for the purpose of preventing the thermal deformation of the cylinder block and also getting high rigidity as a power plant system.

Fig. 13 shows the deflection of crank journal housing center with two cases—that is, when the cylinder head is assembled (● and + of solid line in the figure) and when the hot water of 100°C is

circulated (● and ▲ of dotted line in the figure). Aluminum oil pan plays a significant role to suppress deformation of cylinder block in assembled condition as well as in warmed up condition and to reduce engine friction.

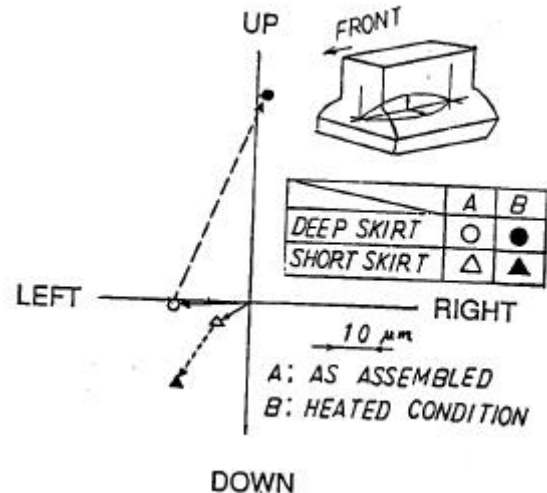


Fig. 13 Deflection of Crank Journal Housing Center

Results of laser holography of the block static rigidity (the block deformation characteristics where a hydraulic pressure is statically applied into the combustion chamber at the compression top dead center in each cylinder) are shown in Fig. 14. The 1FZ-FE engine is ensured of sufficient rigidity equivalent to that of other in-line 6 engines.

The weight reduction of 5.5Kg is also attained compared with the deep skirt type, by adopting aluminum upper oil pan. An engine oil level sensor is installed in the upper oil pan so that the warning can be given when the oil level becomes low.

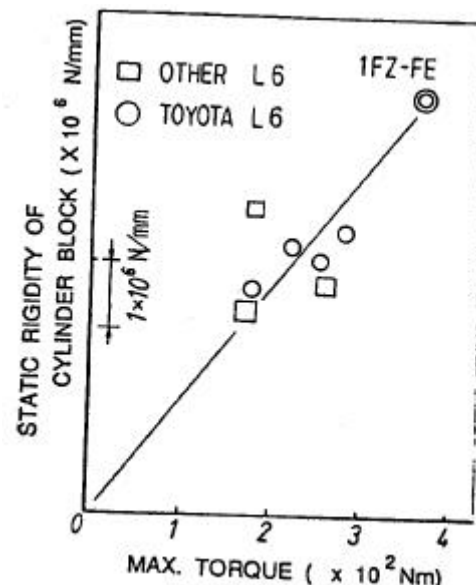


Fig. 14 Static Rigidity of Cylinder Block

CRANKSHAFT

7-journal and 12 balance weight type crankshaft is used and high rigidity is ensured by the optimization of the journal diameter ,pin diameter and the shape of arms.

CONNECTING ROD

The connecting rod is subjected to double-shot peening after the hot forging,to have weight reduction and the reinforcement of strength. The connecting rod bolt is tightened in plastic region,in order to allow the weight reduction and higher reliability.

COOLING SYSTEM

A thermostat with the bottom bypass system is installed on the water inlet side.

Eight blade fan is used,with the diameter of 470mm,which are combined with a fan coupling of three stage temperature-controlled type. This system is efficient not only for the noise reduction but also for the fuel economy.

INTAKE MANIFOLD

The length of intake air system is selected to be long and identical between cylinders, (intake system length;400mm). Owing to this design, the engine shows very flat torque characteristic in wide speed range.

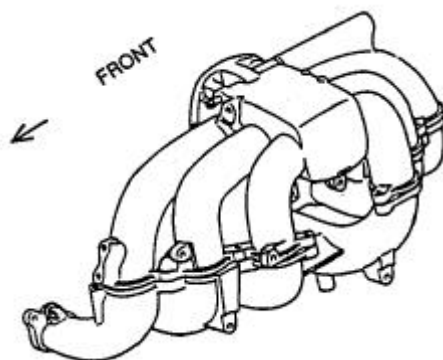


Fig.15 Intake Manifold

LOW NOISE AND VIBRATION

The vibration and noise level have been lowered by the introduction of the highly rigid cylinder block, 12 balance steel crankshaft, aluminum oil pan, etc. Fig.16 shows the comparison of noise level at the distance of 1 m from the engine with the deep skirt cylinder block under development, the short skirt block+aluminum oil pan in production and the 3F-E engine.

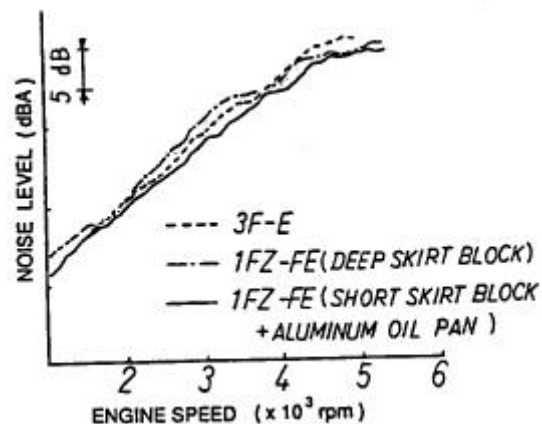


Fig. 16 Noise Level

HIGHER FUEL ECONOMY

The compact combustion chamber (pent-roof shape, center-located ignition spark plug, compression ratio of 9.0 are used), reductions of frictions of moving parts and the optimization of intake /exhaust systems have contributed to the excellent fuel economy.

Fig.17 shows the test results. The fuel economy of the 1FZ-FE engine has been obtained approximately 10% improvement over the 3F-E engine.

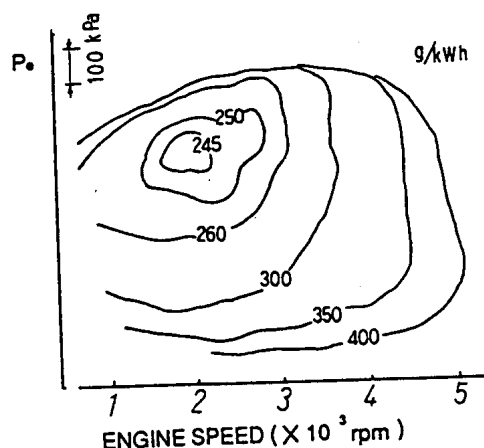


Fig.17 Characteristic of Fuel Consumption

ENGINE CONTROL SYSTEM

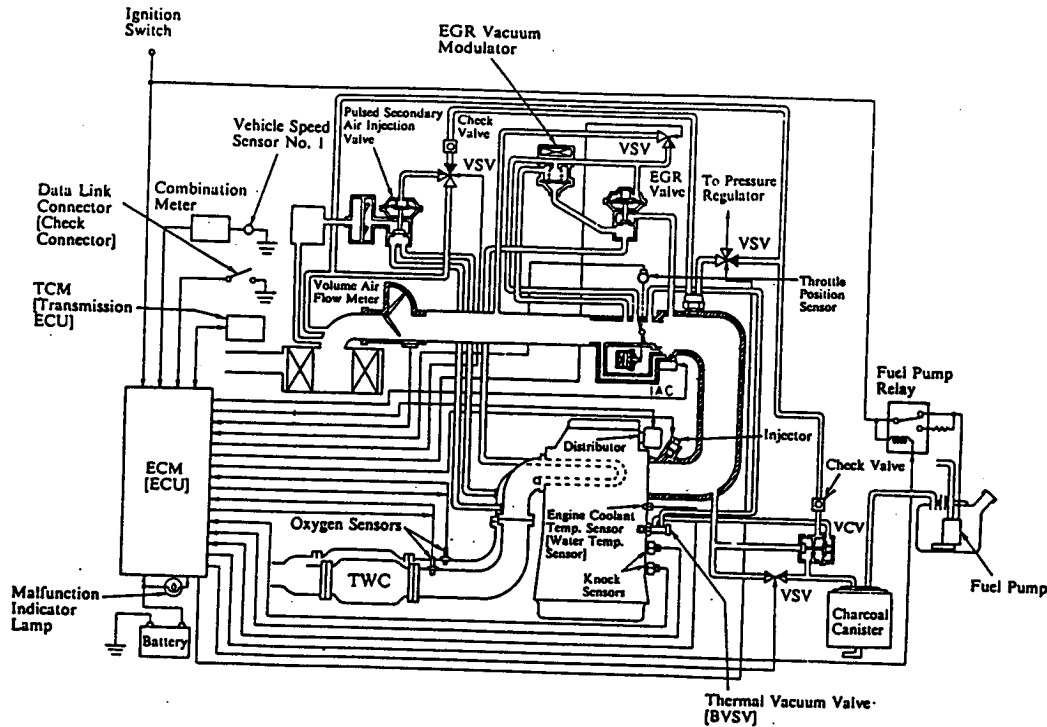


Fig.18 Engine Control System

Fig.18 shows the engine control system. The (Electric Control Module) controls ESA(Electric Spark Advance), SFI (Sequential Fuel. Injection), EGR, PAIR (Pulsed Secondary Air Injection), IAC (Idle Air Control), etc.

The EGR limit is extended by 4% compared with the simultaneous fuel injection. Fig. 19 shows the test results.

KCS (Knock Control System)

The KCS consists of two knock sensors installed onto the block side wall above #2 and #5 cylinder walls.

The KCS is capable of accurate detection of knocking in each cylinder, and controlling the ignition timing to the trace knock condition. The higher power and the lower fuel consumption have been thus attained.

SEQUENTIAL FUEL INJECTION

The fuel is injected sequentially to individual cylinder, which synchronizes with the intake stroke of each cylinder to terminate injection just before intake valve opens.

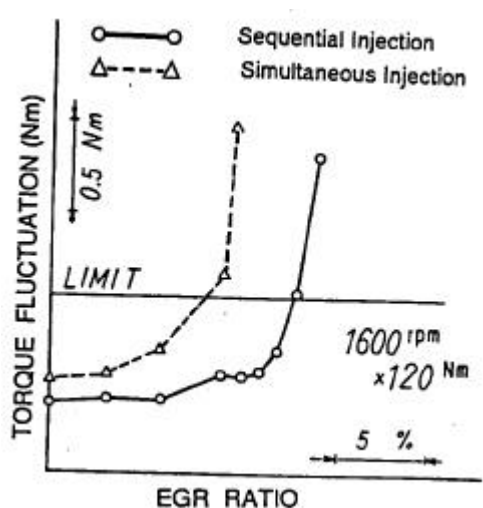


Fig. 19 Effect of Sequential Fuel Injection

CONCLUSION

The 1FZ-FE engine has a collective essence of Toyota's technologies accumulated over years. It is developed as an engine more suitable for the Land Cruiser. The high power performance, low fuel consumption, light weight and high reliability of the 1FZ-FE engine have been assured owing to the development efforts made by the authors, et al, who intend to strive for further enhancements of this engine.

REFERENCE

(1) T.Hosokawa, et al. , SAE paper 890775, 1986.