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ABSTRACT

Mitsubishi has developed the new, compact, water-cooled vertical type 2-cylinder diesel engine model K2AS and brought it to market in spring of '82. The K2AS is a small-sized engine of 451 cc total displacement and 10HP/3600 rpm maximum output. Its weight of 58 kg is light enough to use this diesel engine for various machines which have formerly been driven by gasoline engines.
The well matched combustion chamber and injection system realize low fuel consumption, low noise and easy engine starting. High durability is also assured by various kinds of reliability evaluation.
Features of K2AS are outlined below.

ARISING FROM THE FIRST OIL CRISIS in 1973 the use of diesel engines in place of gasoline engines became necessary from the view point of saving petroleum resources, energy and running cost. That tendency became decisive through the second oil crisis in 1979.
Mitsubishi is developing and producing a wide variety of diesel engines including the "Katsura engine"(compact single-cylinder water-cooled horizontal diesel engines) and the powerful 4-cylinder vertical diesel engines. Mitsubishi diesel engines are well received by worldwide users as engines widely applicable to agricultural, industrial and marine uses.
On the basis of experience in production of compact vertical water-cooled diesel engines ranging from 566 cc to 1490 cc and from two to four cylinders, Mitsubishi has now successfully developed this very compact, light weight diesel engine of 451 cc total displacement, 10HP/3600 rpm maximum output and 58 kg in weight.
The new engine is far more compact than conventional water-cooled diesel engines and, therefore, is able to take the place of air-cooled gasoline engines as shown in Fig.1.

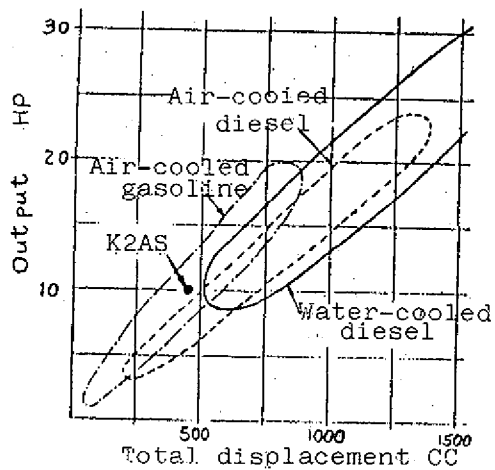

Fig.1. Output range of gasoline and diesel

TARGET OF DEVELOPMENT AND FEATURES

K2AS aims at the market for single-cylinder air-cooled gasoline engines ranging from approximately 400 cc to 550 cc and single-cylinder air-cooled diesel engines.

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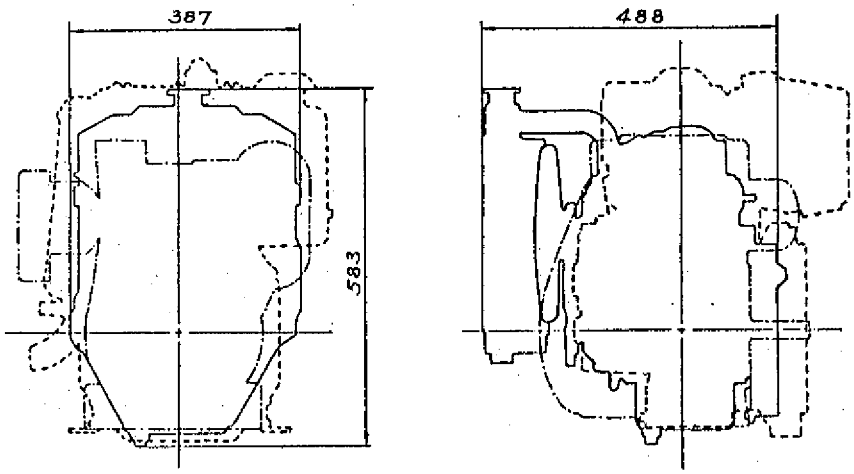
The target of development and features of K2AS engine are as follows:

1) Compactness and light weight
   K2AS realizes a two-cylinder water-cooled diesel engine comparable in compactness and lightness with single-cylinder air-cooled gasoline engines.
   Fig.2. shows the dimensions of K2AS in comparison with conventional air-cooled gasoline and diesel engines.

Fig.2
Comparison of dimension

——— K2AS
—-—-— Air-cooled gasoline
----- Air-cooled diesel



   As clearly seen in the figure, the size of K2AS equipped with a radiator is small enough to compare with ordinary single-cylinder air-cooled diesel engines. It has very small width. Although the overall length of K2AS is somewhat larger than that of air-cooled engines,it does not exceed the allowable limit of overall length in which an engine can be mounted on a machine. Lightness of K2AS,weighing 58 kg including its AC generator and starter,is realized by the light-weight design of main moving parts, decrease of cylinder block wall thickness and minimization of the number of component parts. OEM and end users will be satisfied by the compactness and lightness of K2-AS.

2) Low fuel consumption and low noise
   The realization of mild combustion sounds is due to the well matched combustion chamber and injection system. High combustion efficiency accompanies low fuel consumption and improved exhaust characteristic.

3) Easy engine start
   In general small engines are lacking in sureness of starting. In K2AS, easy starting in cold weather is assured by well designed injection system matching or, in other words, by the proper combination of automatic increase of fuel injection at engine start period with automatic retard of injection timing. Also the quick heat type glow plug is adapted to improve sureness of engine starting at normal temperatures. It is possible to install the block heater for meeting the requirement of extremely cold weather engine starting.

4) High reliability
   All engine parts are made of excellent materials selected in close cooperation with Mitsubishi Motors Corporation. Especially for major moving parts and cylinder head gasket, high reliability has been proved by through evaluation including severe laboratory and field tests extended over a period of several thousands hours.

5) Easy maintenance
   Engine maintenance is easy because of small number of component parts and of one-sided arrangement of daily-inspection parts such as the fuel filter, oil filter, oil level gauge, speed control lever and injection pump.

SPECIFICATION OF K2AS

Table 1 shows the specification of K2AS. Fig.3 diagrams engine performance curves.

Model	K2AS
Engine type	4 cycle,water-cooled vertical diesel
Combustion chamber	Swirl chamber type
Number of cylinder	2
Bore x Stroke(mm)	65 x 68
Total displacement	0.451 (lit.)
Compression ratio	25
Size (L x W x H)	393 x 342 x 519 (mm)
Dry weight (kg)	58
Lubrication method	Forced circulation
Oil pump	Trochoid type
Oil filter	Paper element type
Oil capacity (lit.)	2.8(up.)~1.8(low.)
Fuel used	Diesel fuel
Fuel injection pump	Bosch type M
Fuel filter	Paper element
Nozzle	Throttle type
Governor	Centrifugal type
Cooling method	Forced circulation
Water pump	Centrifugal type
Water capacity(lit.)	Approx. 1.6
Starting motor	Solenoid shift type
Alternator	AC type
Glow plug	Sheath type
Regulator	IC rectifier type
Battery	12V,45AH or more

Table.1 Specification of K2AS

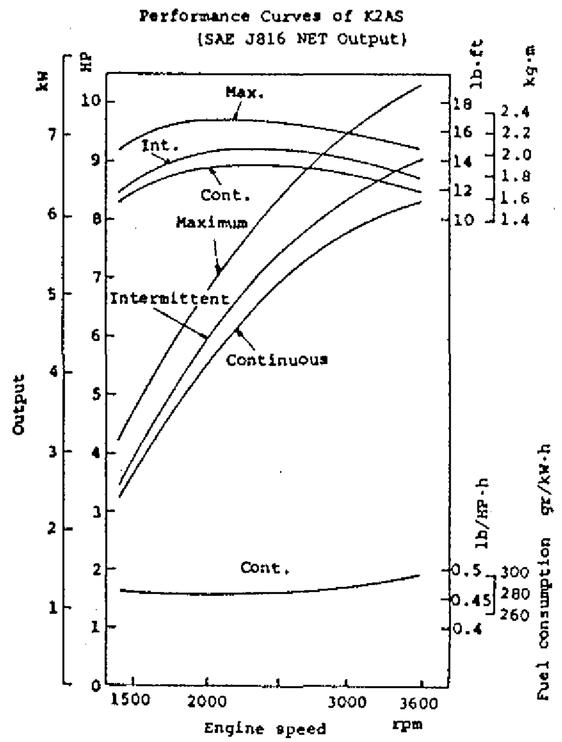


Fig.3 Performance curve

STRUCTURE

Fig.4 shows the cross-section view and Fig.5 shows the longitudinal-section view.

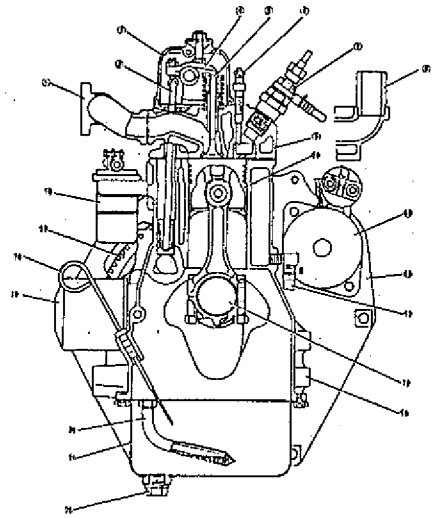


Fig.4 Cross-section view

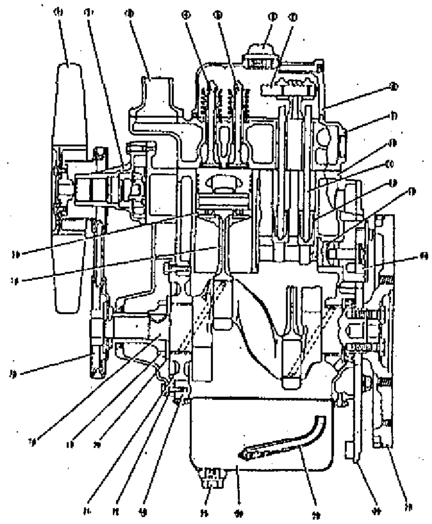


Fig.5 Longitudinal view

1) Combustion chamber and cylinder head

The combustion chamber (Fig.6) is of the spiral type favorable for improvement of noise problem,engine output and exhaust gas characteristic. The optimum specification of the spiral combustion chamber has been determined as the results of many combination tests using a variety of chamber shapes, chamber positions, nozzle hole shapes, nozzle positions and glow plug positions. The finally determined spiral combustion chamber has the following characteristics: Volume ratio 56.9%, nozzle hole area ratio 0.86% and nozzle hole major diameter to

minor diameter ratio 2.0%. The emphasis is laid on proper matching in performance respect.
Adoption of the quick heat type glow plug makes a success of easy engine starting not only in cold weather, but also at normal temperatures. Fig.7 shows the temperature rise characteristic of the quick heat type glow plug in comparison with the conventional type glow plug.
The spiral combustion chamber is made of special heat-resisting alloy and is press-fitted in the cylinder head. The intake and exhaust valve seats are provided with highly wear-resisting seat ring inserts.
Evaluation of the reliability of the cylinder head against cracking in areas between valves and other defects is made by endurance test in which a test engine is subjected to repetitions of short-period severe treatment (called the low-cycle endurance test).
That is, the engine is subjected to the automatically repeated test cycle of 3-minute high-speed, maximum-load condition and 3-minute engine stop condition. In the first 3-minute period coolant stays in the jacket and, therefore, boils quickly causing temperature rise of the cylinder head including the areas between valves. With start of the second 3-minute period, the engine stops automatically and, at the same time, the water feed valve opens to let cold water circulate in the engine. The water cools the cylinder head including the areas between valves to the normal temperature. Then, the engine turns to high-speed, maximum-load running again. This testing method makes it possible to evaluate engine reliability in a short time by applying radical heat shocks to the areas between valves.
In general, it has been actually proved that a marketed engine will be free from cylinder troubles including cracking in the areas between valves if the engine can endure to the end of 500 cycles (50 hrs.) of this test.

2) Cylinder block

The cylinder block is made of highly wear-resistant special cast iron.
The full-jacket type cylinders are formed in the block in one united body. Although standard wall thickness is as small as 3.5 mm, high rigidity is kept by the tunnel structure in addition to the adoption of reinforcement ribs which prevents the occurence of unbalanced vibration modes.
Deformation of the cylinders resulting

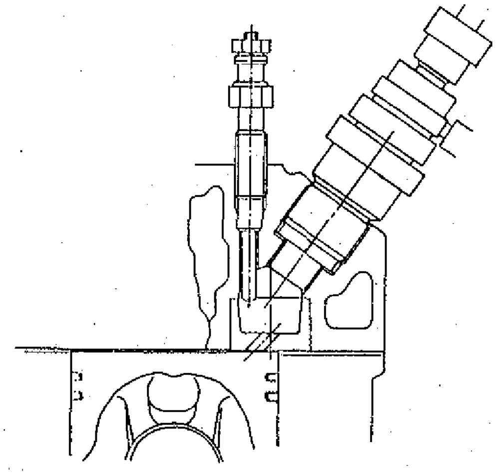


Fig.6 Swirl chamber

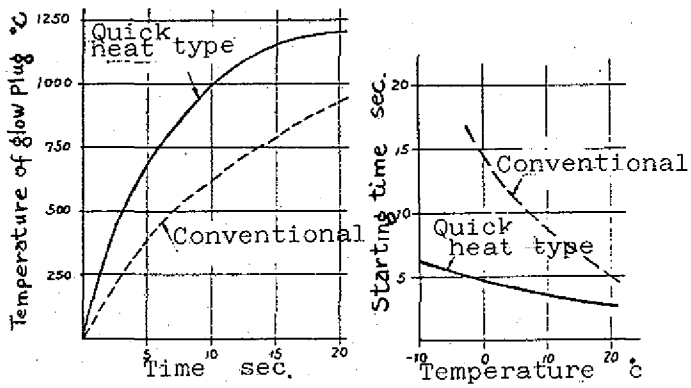


Fig.7 Comparison of glow plug

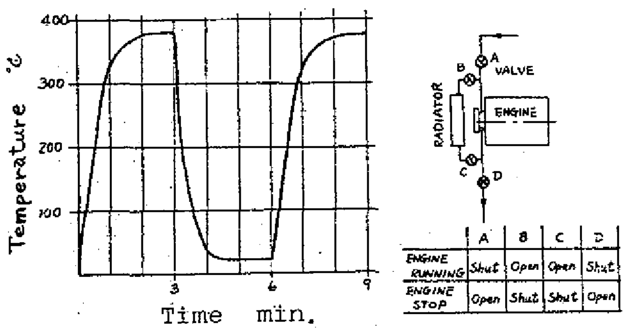


Fig.8 Heat shock test method

from tightening of the cylinder head is negligibly small. Wear of the cylinders is as small as 20μm after 1000 hours of full-load, 3600 rpm continuous endurance test.

3) Main moving parts
The precision-forged crankshaft is made of high carbon steel and its balancers are formed in one united body. The pins and journals are hardened by special heat treatment for sufficient wear resistance and strength. For evaluations of crankshaft strength,the maximum allowable lateral tensile strength is determined by the stress measurement and lateral tensile endurance testing of the actual engines. Furthermore, it is lately under consideration to add a rigidity examination using the finite element method as a new attempt. An example is shown in Fig.9.

4) Valve train
The overhead valve train consists of the cams, tappets, push rods, rocker arms and the intake and exhaust valves. Valve clearance is 0.25 mm when the engine is cold. The camshaft is the high carbon steel forging on which injection pump cams are formed in one united body. The cams and journals are hardened by induction hardening. The camshaft is supported in the machined holes in the crankcase. Oil holes are in the journal to lubricate the cylinder head and rocker arms intermittently.
The rocker arms are light and small hardnable castings, which reduce inertia force of moving parts and have the strength and reliability sufficient enough to withstand high-speed running.

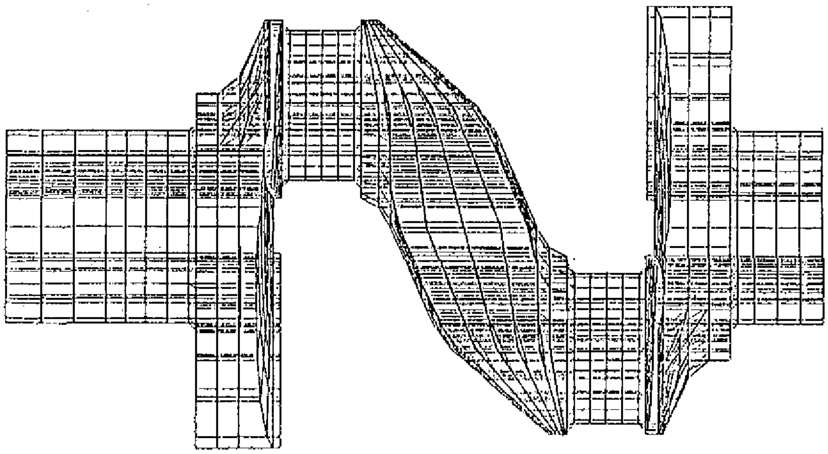


Fig.9 FEM analysis for crankshaft

The pistons are made of special aluminum alloy. The thermal flow type pistons do not cause immoderate heat flow and, therefore, are suitable for high-speed running. The pistons have the barrel type profile which basically falls under the category of elliptical cross section. The optimum profile is determined finally, however, as the results of examination of both the noise-suppression and anti-scuffing properties.
Taken into consideration as the point of evaluation is the deviation of clearance at both high and low piston temperatures. Furthermore, piston temperatures are measured to estimate the possible thermal deformation of pistons and determine the optimum matching with piston rings so that the highly reliable and low noise pistons are realized.
An example of piston temperature measuring method is shown in Fig.10.

5) Injection system
Sureness of engine starting in cold weather has been largely improved by the help of additional functions-automatic increase of fuel injection and automatic retard of fuel injection timing- given to the injection pump.
Fig.11 shows the development of a plunger. Fig.12 shows the principle of plunger operation. The plunger is of the two-stage lead type and the maximum injection quantity is approximately two times as much as that at the smoke-set point. The slot in the plunger provides the retard necessary for the optimum fuel injection timing at engine start. When the speed control lever is set to the "high speed"position at engine start, the injection pump rack is set to the utmost end position by the governor spring force which is applied to the rack through the fork lever. This rack position is indicated as MAXIMUM SET in Fig.10. At this rack position, increase of fuel injection and retard of inject-

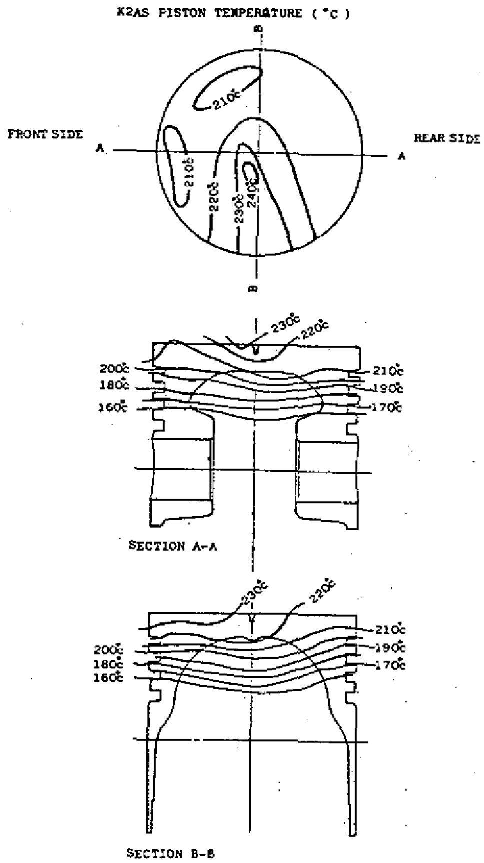


Fig.10 Piston temperature

ion timing are made automatically. Timing retard produces much effect on rising of the speed of rotation of the engine after firing in cold weather, especially when oil viscosity is high or starting load is large, thus providing improved starting characteristic. The increase of fuel injection is effective to improve firing. Fig.13 shows these effects in comparison to an engine having neither increase of fuel injection nor timing retard.

The throttle type injection nozzles have been adopted to suppress noise. This type of nozzle is effective to prevent excessive rise of cylinder pressure by controlling the initial injection ratio, thus realizing mild combution sounds. Noise levels measured at a test point 1 m from the wall of the engine in full-load operation are 86 dB(A) at 2000 rpm, 89 dB(A) at 2500 rpm, 92 dB (A) at 3000 rpm and 95.5 dB(A) at 3600 rpm. Valve cracking pressure of the injection nozzle is 160 kg/cm^2. Atomization of injected fuel is improved to help fuel combustion. The Bosch type delivery valve is favorable to high-speed

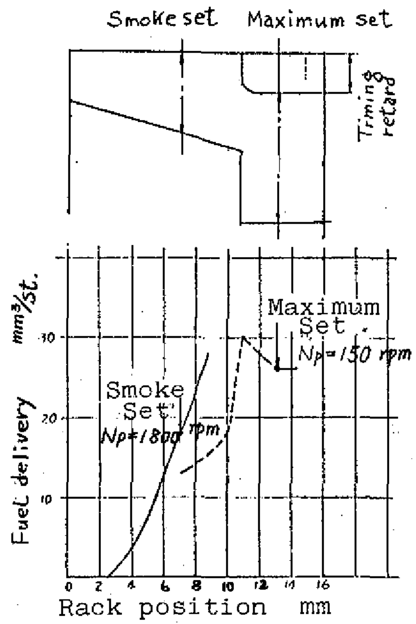


Fig.11 Plunger development

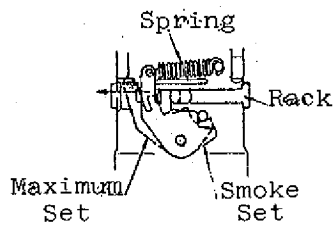


Fig.12 Setting of Smoke set and Maximum set

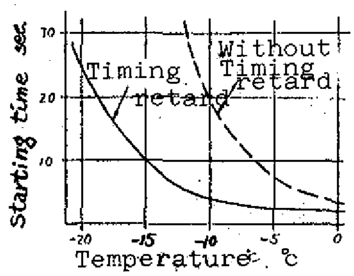


Fig.13 Comparison of startability

running of the engine. Well designed matching with the spiral combustion chamber realizes low noise, low fuel consumption and favorable exhaust gas characteristic.

Fig.14 shows the typical indicator diagram. The results of exhaust gas measurements during normal engine operation are shown in Fig.15, 16 and 17.

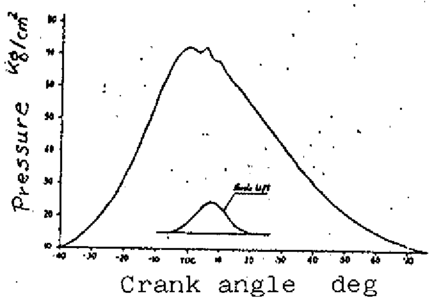


Fig.14. Indicator diagram

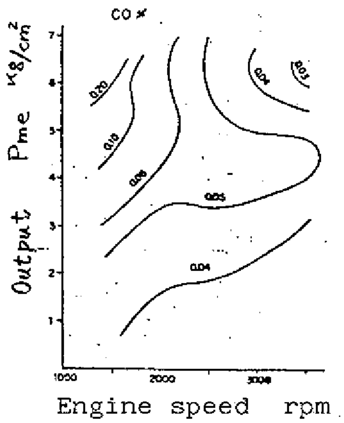


Fig.15 Exhaust emission CO %

6) Cylinder head gasket

The cylinder head gasket is made of carbon-series seat material. Stenless steel grommets are used for gas sealing. Reliability of the gasket has been increased remarkably in comparison with the conventional steel-bestos gasket.The optimum gasket specification is determined in accordance with the flow-side shown in Table 2 and under wide range of testing and examinations including dispersion of products. Main points of testing are as follows:

(1) Dispersion accompanying production is to be taken into consideration when testing. (Physical properties of gasket, upper and lower limits of formed products)
(2) Adoption of proper testing method which allows gasket evaluation in a short time. (Pressure sensitive test, matching test, low-cycle test, etc.)
(3) Adoption of proper testing which takes aged deterioration into consideration.

Fig.18 shows an example of surface pressure distribution by the pressure sensitive testing. Fig.19 shows an example of matching test. Furthermore, matching tests have been performed

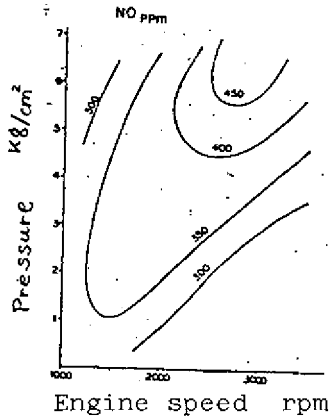


Fig.16 Exhaust emission NO ppm

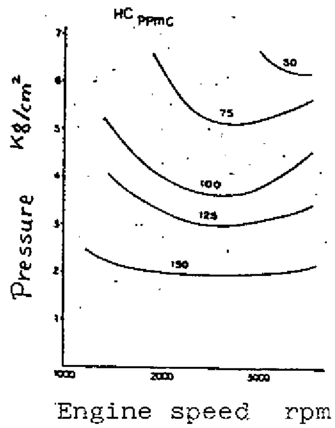


Fig.17 Exhaust emission HC ppmc

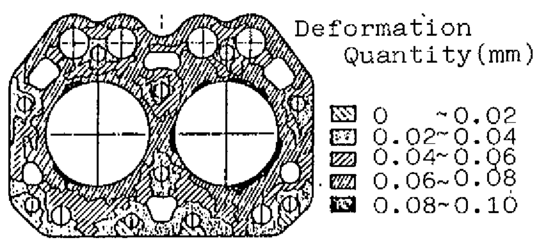


Fig.18 Deformation distribution

before and after the low-cycle endurance test to establish short-period evaluation of gasket.

7) Cooling system

The cooling system is of the forced circulation type always provided with a water pump and it makes uniform cooling of engine component parts possible. Fig.20 shows the results of engine heat rejection measurement.

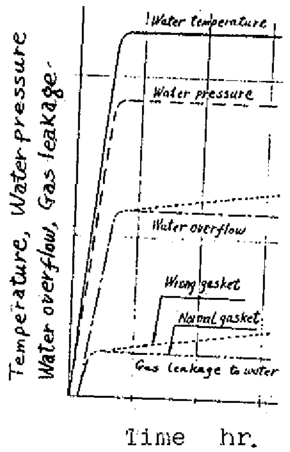


Fig.19 Head gasket matching test

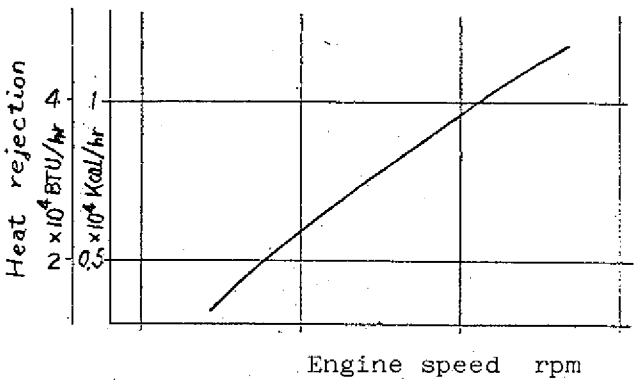


Fig.20 Heat rejection

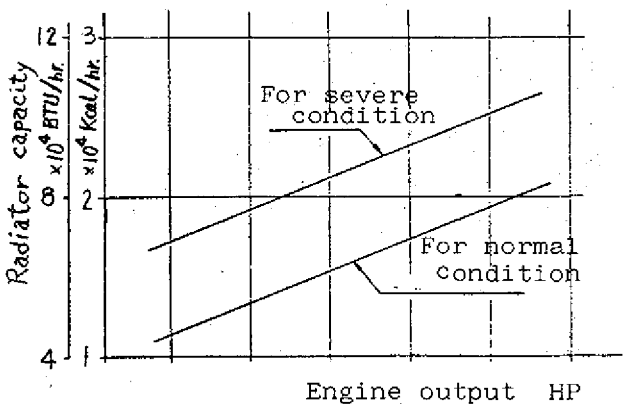


Fig.21 Relation between engine output and radiator capacity

On the basis of such a test results, recommended radiator capacity is shown in Fig.21.
Althouth adequate radiator capacity is dependent on working condition of a machine powered by the test engine, acceptable cooling performance can be obtained if an air-water difference not exceeding 60°c is attained as the target value of heat balance of the test engine which is equipped with all accessories and mounted on the machine.

CONCLUSION

We have developed the compact and light-weight diesel engine model K2AS having the above-mentioned features and brought it to market in spring of 1982 for wide range of applications including generators and welders. The new engine is successfully being well received by users. We intend to continue further improvements of this engine on all sorts of advise and suggestions.

Table.2 Flow chart of gasket test

1. Check 1)manufacturing process 2)material property 3)tolelance
2. Arrangement of trial gasket Meassuring of material property (in this case,gasket of lower limit for gas and water seal)
3. Meassuring of gasket pressure head bolt fasten torque lower limit, lower limit x 0.8
4. Fix 1st. stage specification
5. Matching test
6. Heat shock test
7. Fix 2nd. stage specification
8. Arrangement of re-cofirm gasket 1)normal 2)lower limit for gas and water
8. Meassuring of gasket pressure and material property
9. Final confirm test 1)matching test 2)heat shock test 3)continuous running test
10. Fix final specification
11. Production

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