

Increase of Knock Limit in Outboard Motor Through Employment of Dual Control Direct Cooling System

Yoshihiko FUKUDA*

Hiroki TAWA*

Atsuo MAKISE*

ABSTRACT

Cooling performance of the outboard engines, which pump ambient water to cool the engine and discharge it, has been improved in a direct-cooled outboard motor without a radiator in order to increase knock limit.

The research project leading to this improvement tested a conventional single control cooling system and a new dual control cooling system in which the cylinder head and cylinder block were made independent and each were provided with a thermostat to enable temperature to be controlled.

Tests were conducted under full engine load. Measurements of the temperature of the cooling water inside the water jacket were taken to evaluate the cooling performance. Knock limit was evaluated through measurements of the combustion chamber pressure using a gasket type combustion pressure sensor positioned at the spark plugs.

These measurements confirmed that the dual control cooling system increased knock limit by 8 deg against the conventional single control cooling system.

1. Introduction

With the growing concern for environmental issues in recent years, the transition from the conventional 2-stroke engine to the 4-stroke engine is progressing rapidly in the outboard motor market. On the other hand, compactness and high output equivalent to the 2-stroke engine are demanded in engine size and power, and further improvements are also being demanded in fuel consumption and emissions.

Improving the knock limit is one method to address these issues. If the knock limit is improved, the ignition timing can be set closer to the MBT (Minimum advance for the Best Torque: the ignition timing at which output and fuel consumption rate become optimum), and increased output

together with improvement in fuel consumption through high compression can be expected. One method of improving the knock limit is to reduce the temperature of the combustion chamber by enhancing the cooling performance of the cylinder head.

An indirect cooling system is employed in normal water-cooled engines for automobiles, in which the cooling water is circulated in the closed cooling water circuit to cool the engine, and is cooled using heat exchanger including radiator. This cooling water system is mainly a single control cooling system in which the cooling water flows from the water pump to the cylinder block, cylinder head, radiator, and thermostat. Studies have already been conducted on the dual control cooling system in which the temperature of the

* Asakahigashi R&D Center

cylinder head is reduced effectively by controlling the temperature individually using separate routes for the cylinder head and cylinder block systems to improve the knock limit as mentioned above. The effects of this system have already been reported^{(1), (2), (3)}.

As opposed to automobile engines, existing water-cooled engines for outboard motors employ a direct cooling system. In this system, water from the sea or river in which the boat navigates is sucked in and used for cooling the engine and then discharged. This cooling system is also generally a single control cooling system where the cooling water flows from the water pump to the exhaust manifold, cylinder head, cylinder block, thermostat, and the outlet. If the dual control cooling system mentioned above is employed, the cooling performance of the indirect cooling system can be effectively improved, as the difference in the water temperature in the cooling water intake and the cylinder head temperature is higher than in the indirect cooling system.

This paper describes the characteristics and the effects of improving the knock limit when the dual control cooling system is used in water-cooled engines for outboard motors.

2. Issues with the Conventional System and Goals

Preventing overheating of the engine during Wide Open Throttle (hereafter referred to as WOT) operation and inhibiting oil dilution due to excessive cooling during idling operation (hereafter referred to as trolling) should be considered in direct cooling systems to be used in engines for outboard motors. Measures for preventing overheating during WOT operation include setting a low thermostat temperature to reduce the overall temperature. However, the temperature of the cylinder block needs to be high for inhibiting oil dilution during trolling.

If oil dilution occurs, the lubricating ability deteriorates and the engine may seize due to deterioration in the properties of the lubricating oil; therefore, inhibiting oil dilution is a priority. To inhibit oil dilution, the thermostat temperature is set such that the cylinder block temperature is maintained at a high level but outside the range of overheating. The cooling water flows sequentially to the exhaust manifold, the cylinder head, and then to the cylinder block. Means are also provided for raising the cooling water temperature before cooling the cylinder block. On the other hand, reducing the cylinder head temperature is one method for improving the knock resistance. However, the cylinder head temperature is high due to the above-mentioned reasons and this reduces the knock resistance, affects the advance in the ignition timing, and hinders the increase in output.

Accordingly, the dual control cooling system with means for separately controlling the temperature and satisfying cooling performance with conflicting requirements, namely

- (1) Maintaining the status of cylinder block temperature and
- (2) Reducing the cylinder head temperature.

Figure 1 shows the cooling water circuit for the single control cooling system.

3. Construction and Characteristics of the Dual Control Cooling System

Two changes were made to the conventional single control cooling system to realize the dual control cooling system.

The first change is to completely isolate the cooling water circuits of the cylinder head and cylinder block using a cylinder head gasket, make them separate and control the water temperature in each circuit using a thermostat. With this change, thermostat-controlled temperature of the cylinder head and cylinder block could be set individually, enabling an optimum controlled temperature to be set for each.

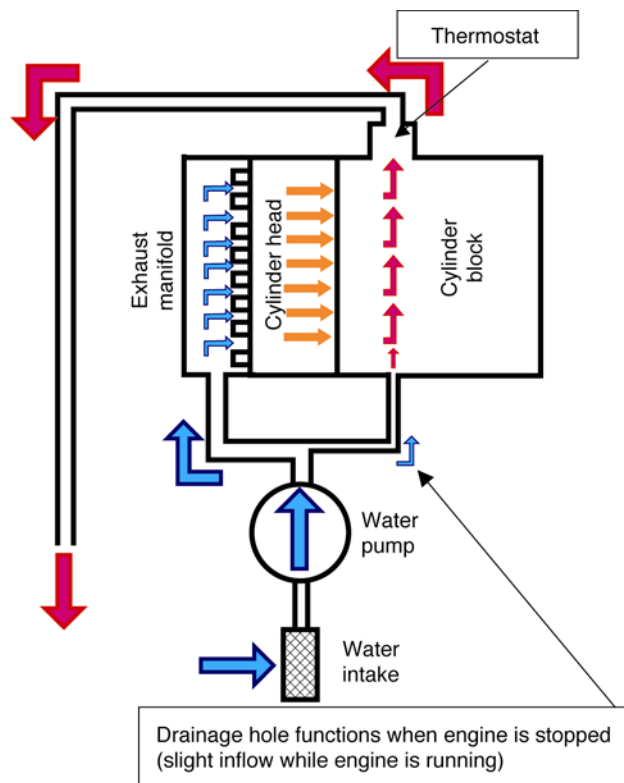


Fig. 1 Cooling water route for single control cooling system

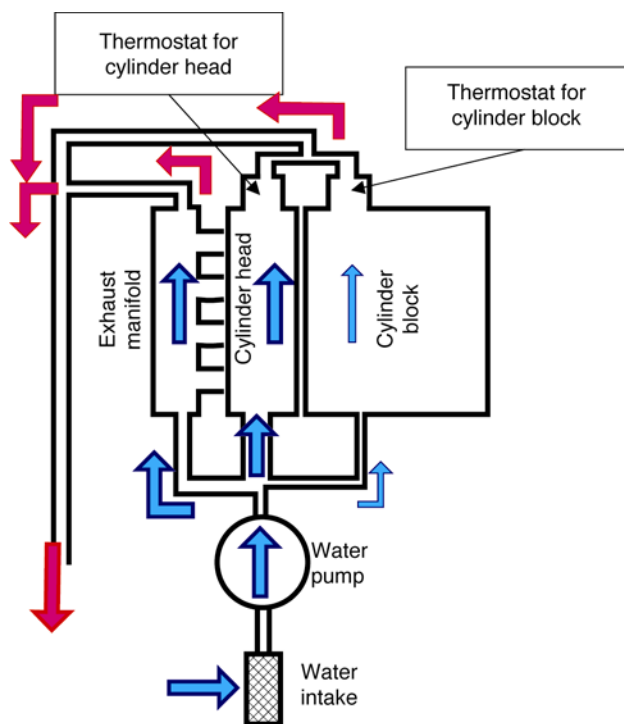


Fig. 2 Cooling water route for dual control cooling system

The second change is that a cooling water circuit was installed for the exhaust manifold completely separate of the cooling circuit for the cylinder head and cylinder block. This circuit introduced cooling water from the lowermost part of the cylinder head and cylinder block.

With this construction,

- (1) The cylinder head cooling water is not routed through the exhaust manifold; therefore, the water temperature at the cylinder head intake is reduced.
- (2) The cooling water flow is simplified by routing it from bottom to top, thus avoiding stagnation of cooling water.

The temperature of the cooling water in the water jacket of the exhaust manifold is not controlled by the thermostat. Figure 2 shows the circuit diagram of the dual control cooling system.

4. Effects of Dual Control Cooling System

4.1. Test Conditions

4.1.1. Test engine specifications

Table 1 shows the main specifications of the test engine used in all the tests.

4.1.2. Environmental conditions for tests

Table 2 shows the environmental conditions for the tests.

4.1.3. Temperature measurement points

Figure 3 shows the temperature measurement points on the cylinder head.

4.2. Effects of Cooling Performance

In these tests, a 60 °C thermostat was mounted for the test engine with the single control cooling system. For the test engine with the dual control cooling system, 50 °C thermostat and 60 °C thermostat were mounted on the cylinder head and cylinder block, respectively. The water temperature in the water jacket in the cylinder head was measured in order to compare the cooling performance. Figure 4 shows the cooling water temperature in the cylinder head for each cylinder in the single control cooling system when the engine was operated with water temperature of 15 °C, ambient air temperature of 20 °C, and WOT of 6 000 rpm. Figure 5 shows the cooling water temperature in the cylinder head in the dual control cooling system under similar conditions.

Table 3 shows the results of the comparison of Figs. 4 and 5.

As shown in Table 3, the water temperature in the water jacket of the cylinder head could be reduced on average by 23 °C at eight locations by changing over from the single control cooling system to the dual control cooling system.

Figure 6 shows the relationship between the thermostat set temperature and the oil dilution rate.

The relationship between the oil dilution rate due to dilution after 50 hours of trolling and the thermostat set temperature is shown by the blue line for the test engine with the single control cooling system. In the dual control cooling system, the thermostat fixed on the cylinder head side is set at 50 °C and the thermostat fixed on the cylinder block side is set at 60 °C, similar to the single control cooling system. The oil dilution rate after 50 hours of trolling is shown by the star mark.

From these results, it was confirmed that even if the

Table 1 Engine specifications

Engine type	4-stroke vertical L-4 cylinder
Displacement (cm ³)	2354
Bore (mm) × stroke (mm)	87 × 99
Combustion chamber form	Half-globular
Compression ratio	9.6 : 1
Valve train	DOHC VTEC 16 valve
Number of valves	4/cylinder
Fuel supply system	Programmed fuel injection
Ignition system	Programmed ignition (with Plug hole coil)

Table 2 Environmental condition for tests

	WOT running	Trolling running
Air temperature	20°C	10°C
Cooling water temp at water intake	15°C	5°C

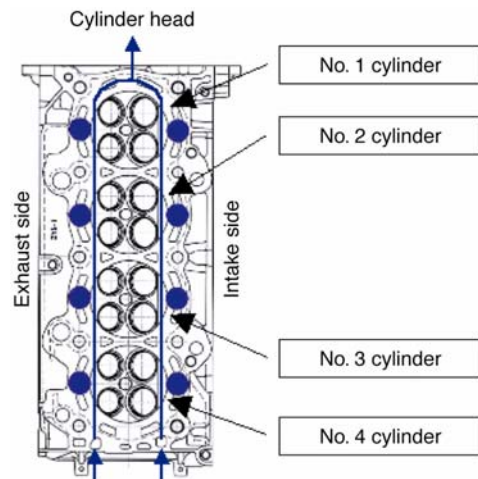


Fig. 3 Temperature measurement points

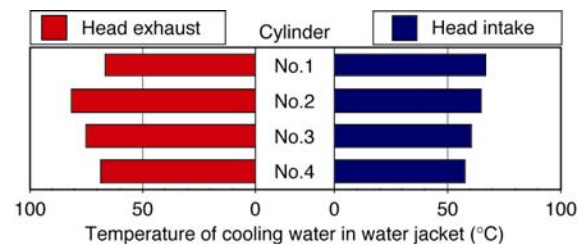


Fig. 4 Single control cooling system

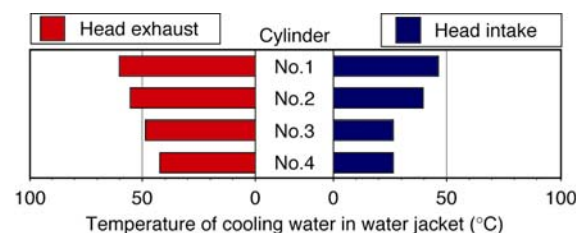


Fig. 5 Dual control cooling system

Table 3 Comparison of temperature in head

	Single control	Dual control	Mean effect
Intake side (4 points avg)	63 °C	37 °C	-26 °C
Exhaust side (4 points avg)	74 °C	54 °C	-20 °C
All 8 points avg	68 °C	45 °C	-23 °C

thermostat set temperature for the cylinder head is lowered by 10 °C from 60 °C to 50 °C, the oil dilution rate is almost unchanged, and this setting does not have a negative effect on dilution.

4.3. Effects of Output Performance

4.3.1. Improvement in knock limit by using the dual control cooling system

The improvement in knock limit was evaluated by using the dual control cooling system.

Figure 7 shows the comparison of the knock limits up to an engine speed of 4 500 to 6 000 rpm with WOT operation.

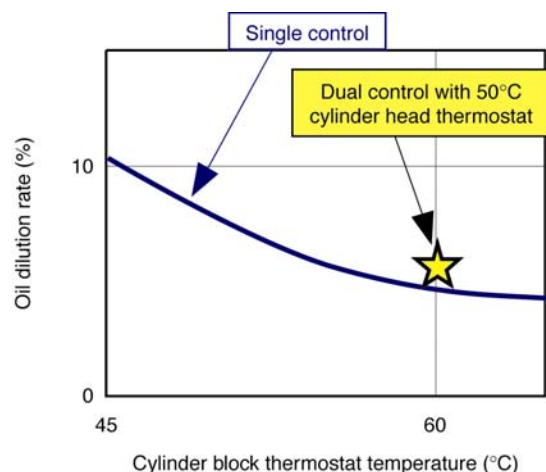


Fig. 6 Thermostat set temperature and oil dilution rate

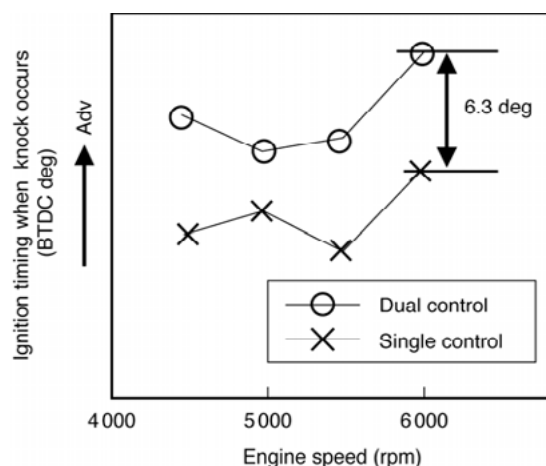


Fig. 7 Comparison of ignition timing when knock occurs single and dual control cooling systems

This test was performed on a completed engine with a gear case assembly. The conditions were identical for important parameters in the knock limit such as the compression ratio, intake air temperature, volumetric efficiency, and air fuel ratio.

The thermostat temperature was set at 60 °C in the single control system test engine. The thermostat temperatures of the cylinder head and cylinder block were also set at 60 °C respectively, in the dual control cooling system test engine.

By changing the single control cooling system to the dual control cooling system, the knock limit is improved by 6.3 deg at an engine speed of 6 000 rpm.

This is the effect of improvement of the cooling performance by changing to the dual control cooling system and eliminating stagnation of cooling water in the cylinder head.

4.3.2. Improvement in knock limit due to the low temperature of the head cooling water

Various studies have been conducted on the cylinder head and cylinder block in the dual control cooling system. It is generally known that the knock limit and the volumetric ratio improve due to the low temperature of the cooling water in

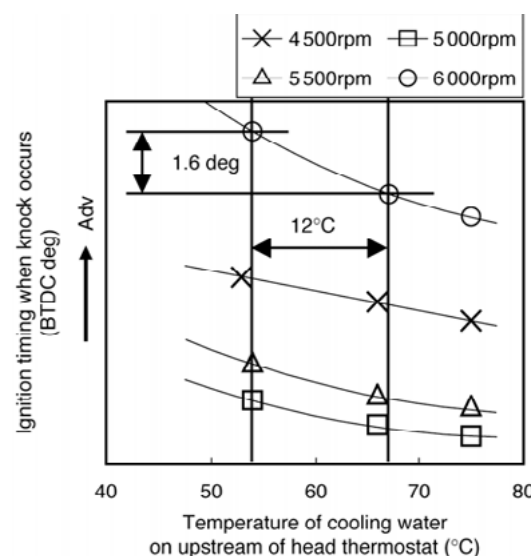


Fig. 8 Effect of cooling water temperature on ignition timing when knock occurs with WOT

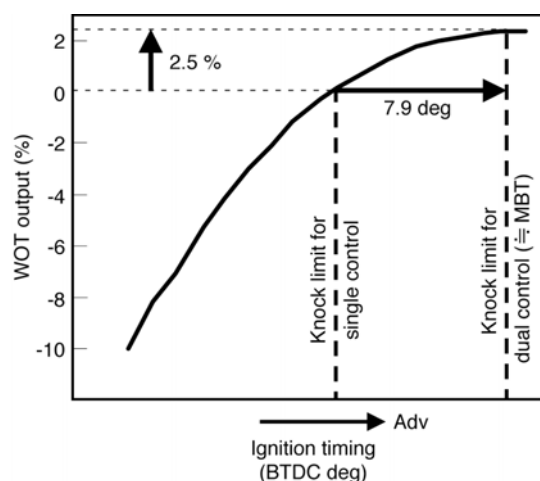


Fig. 9 Correlation between WOT output and ignition timing (6 000rpm)

the cylinder head. Figure 8 shows the temperature of the cooling water upstream of the thermostat on the cylinder head side and the ignition timing when knock occurs. The thermostat on the cylinder block side was set at a constant temperature of 60 °C and only the temperature of the thermostat on the cylinder head side was varied in steps of 10°C from 50 to 70 °C at 4 500 to 6 000 rpm with WOT. As shown in Fig. 8, if the thermostat set temperature is reduced by 10 °C, the temperature cooling water upstream of the thermostat on the cylinder head side is reduced by 12 °C. As a result, the knock limit improves by 1.6 deg during WOT operation at the engine speed of 6 000 rpm.

4.3.3. Increase in maximum output with the improvement in knock limit

As mentioned above, if the 6.3 deg for the improvement in knock limit due to the dual control cooling system is combined with the 1.6 deg for the improvement in knock limit due to the lowering of water temperature by 10 °C, from 60 °C to 50 °C, in the thermostat set temperature on the cylinder head side, the ignition timing could be advanced by a total value of 7.9 deg.

Thus, an increase in output of about 2.5% could be achieved.

Figure 9 shows the correlation between the ignition timing and the output.

5. Conclusion

By changing the cooling system from the single control cooling system to the dual control cooling system, the knock limit improved, resulting in an increase in output of about 2.5%.

Further, it was confirmed that the dual control cooling system could be introduced in outboard motors with minor modifications, although the construction may become complex if the system is used for indirect cooling of the engine.

References

- (1) Kobayashi, H., Yoshimura, K., Hirayama, T.: A study on dual circuit cooling for higher compression ratio, IMechE/SAE, International Conference on Fuel Efficient Power Trains and Vehicles London, C427/84, p. 151-158 (1984)
- (2) Yamada, T., Furuno, S., Kanda, M., Iwashita, Y., Yokoi, Y., Katagiri, J.: Improvement of Coolant Flow for Reducing Knock, 1990 JSAE Annual Congress Proceedings Fall, 902, Vol. 1, p. 189-192 (1990) (in Japanese)
- (3) Ishida, N.: System Sekkei to Engine Seinou, Kouseinou Engine to ha Nanika, Tokyo, Grand Prix, p. 210-216 (1991) (in Japanese)

■ Authors ■



Yoshihiko FUKUDA



Hiroki TAWA



Atsuo MAKISE