

Development of New BF90 Outboard Motor

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ABSTRACT

Honda has developed an all-new mid-sized outboard motor in the 4-stroke outboard motor series, the new BF90. Development of the new BF90 stressed enhancements to operating performance and fuel economy.

The new 2006 BF90 uses a SOHC 2-stage VTEC and a dual independent circuit control cooling system. With refinements to the intake system general specifications, including the intake manifold and air silencer, this outboard motor achieves a 13% higher specific power (kW/L) than the current BF90. Fully considering the ways in which outboard motors are used, an open-loop lean burn control system, which uses oxygen sensors, was adopted, raising fuel economy by 20% over the current BF90. At the same time, the motor complies with 2008 CARB emission regulations and the 2006 European Recreational Craft Directive's regulations.

Modifications to the gear case shape have reduced water resistance. This, combined with a reduction in total motor weight, has enhanced operating performance. When used with an aluminum fishing boat, this new BF90 motor achieves 0-200 m acceleration 0.9 seconds faster than in the current motor, and a maximum speed that is 4.6 km/h higher.

1. Introduction

Mid-sized outboard motors (above 37 kW [50 hp] and below 74 kW [100 hp]) account for approximately 18% of all outboard motors in the world market (FY05; Honda research), totaling approximately 119 000 units. With an increasing awareness of fuel economy, comfort, and environmental conservation, the market for this class is becoming stronger, together with an overall market expansion.

In 1995, Honda launched the carburetor model BF75/90. Now, however, Honda has developed a new fuel injection (referred to as FI hereafter) model BF90, which surpasses the current BF90 in terms of being both economical and environmentally friendlier. It also provides enhanced operating performance through higher power and a reduction in operating resistance.

The external design of the new motor is a successor to the Wing Form, based on the integrated lines found in the BF225 and BF150, completing the design lineup of Honda's mid-sized and large outboard motors. Figure 1 is a photograph of the BF90.



Fig. 1 External view of new BF90

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Table 1 Specifications

Code name	New BF90 L-type
Overall length (mm)	740
Overall width (mm)	440
Overall height (mm)	1570
Transom height (mm)	537
Dry mass (kg)	165
Engine type	4-stroke L-type 4-cylinder
Displacement (cm ³)	1496
Bore (mm) × stroke (mm)	73 × 89.4
Compression ratio	9.7:1
Valve train	SOHC VTEC 16 Valves
Valve number	4/cylinder
Maximum power (kW/rpm)	66.2/5800 (90PS/5800rpm)
Maximum torque (N·m)	127
Recommended engine speed range (rpm)	5300 - 6300
Fuel supply system	Programmed Fuel Injection
Ignition system	Programmed Ignition (with Plug Top Coil)
Charge output (A)	35
Cooling system	Water cooling (with 2 thermostats)
Exhaust system	Through propeller hub

2. Main Specifications and Overview

The main specifications of the new BF90 are given in Table 1. The engine uses the 1.5 L in-line 4-cylinder engine⁽¹⁾ used in the 2005 model FIT as a base. A 4-valve SOHC system, which features a 2-rocker arm VTEC mechanism⁽²⁾ on the intake side only, is used for the new valve system.

3. Enhancing Engine Performance

3.1. Increasing Engine Power

The new BF90, in a first for an outboard engine, uses an SOHC 2-stage VTEC engine with a shared rocker shaft for both intake and exhaust. In addition, as a result of an air fuel ratio tuning, adoption of a knock control, and the loss reduction in the fully equipped state by using air intake refinements and the dual independent circuit control cooling system⁽³⁾ adopted on the BF150, higher output was achieved across the entire range. Though the displacement was reduced to 1496 cm³ from that of the current BF90's 1590 cm³ (Fig. 2).

3.2. Enhancing Fuel Economy

3.2.1. Lower fuel consumption achieved through lean burn

The new BF90, like the BF150, implements lean burn control to achieve lower fuel consumption. The BF150 was the first outboard motor to use lean burn control⁽³⁾

with linear air fuel ratio (LAF) sensors. In the BF90, an open-loop lean burn control system with an oxygen sensor was used to reduce cost. As a result, fuel economy was enhanced by 20% over that of the current BF90 (Fig. 3).

Moreover, by making the air fuel ratio (referred to as A/F hereafter) a lean 18:1 in the frequently used cruising speed range, an advantage was gained over other companies' motors in terms of practical fuel economy. Figure 4 is a graph of fuel consumption during operation.

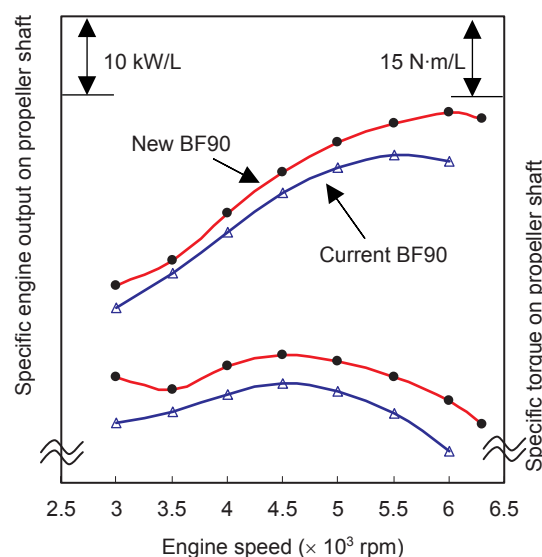


Fig. 2 Specific power and torque of BF90

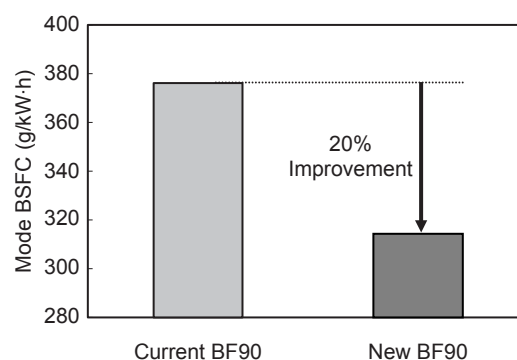


Fig. 3 BSFC in emission measuring mode

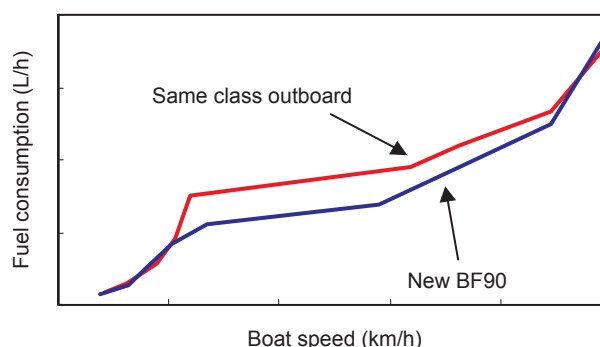


Fig. 4 Fuel consumption at cruising speed

3.2.2. Lean burn control using oxygen sensors

The new BF90 uses an oxygen (referred to as O_2) sensor instead of the LAF sensor used in the BF150. LAF sensors and O_2 sensors have difference in sensor output characteristics. Figure 5 shows these output characteristics. LAF sensors can detect A/F over a wide range, using sensor control circuits, including attached microcomputers. In contrast, O_2 sensors show an abrupt change in electromotive force of the sensor element at the stoichiometric air fuel ratio boundary, so it is only possible to judge whether the ratio is rich or lean. With an O_2 sensor, it is impossible to correct the fuel injection amount using feedback control.

Therefore, for the new BF90, a basic injection quantity map has been prepared for the stoichiometric air-fuel ratio aims, with engine speeds and load (intake manifold pressure) as the parameters. An open-loop lean burn control is used that determines the fuel injection amount at the time of lean burn by multiplying it by the target lean coefficient (equivalence ratio). This makes it possible to have lean burn operation without the use of expensive LAF sensors.

However, with this method, small errors in the basic injection quantity map lead directly to mismatches in the air-fuel ratio during lean burn operation, so accuracy of this map is extremely important. To ensure this accuracy, the following controls are carried out:

In the operation range assuming lean burn operation, once a feedback operation is carried out with the stoichiometric air-fuel ratio, the basic injection quantity map is corrected based on the oxygen sensor output, and the corrected amount is calculated. The correction values are recorded in nonvolatile memory as learned values for each of the ranges when the operating range is divided into eight segments in the engine speed direction. These values are saved, even after the engine stops.

The reason the operating range is not divided in the load direction is derived from the unique outboard motor cruising load characteristics. Unlike motorcycles or automobiles, for outboard motors without a gear shift device, when the boat and propeller used are determined, the relationship between engine speed and load is almost

uniquely determined, as shown in Fig. 6. That is to say, a load at a particular engine speed does not change much during steady operation, so it was determined that optimizing learning values for load direction would be unnecessary.

In this way, by segmenting the correction value for each operation range and optimizing, the accuracy of the basic injection amount map is enhanced.

The learning values determined in this way are used to correct the basic injection quantity map during lean burn operation. Corrected-value calculations involve establishing representative engine speeds within each learning range, with the learning values then determined by linear interpolation at the representative points.

The conditions for shifting to lean burn operation are that engine warm-up is complete, that it is within the range subject to lean burn operation, that there is steady operation, and that there has been an update to learned values in the learned range divided into 8 according to engine speed.

In a certain learning range, if a learning value of the basic injection quantity map correction amount moves from the updated learning range to another learning range in which the learning value has not yet been updated, lean burn operation stops and operation is carried out with the stoichiometric air-fuel ratio. After the learning values are updated, the unit shifts again to lean burn operation. In addition, if the learned values are updated in all lean burn ranges, even if there are learning range changes during lean burn operation, the learning values in each range are used, and lean burn operation continues.

With the learning value and lean burn operation condition settings as described above, the air-fuel ratio (A/F) deviation during lean burn operation can be kept to $A/F = 18 \pm 0.5$, which is also favorable in terms of drivability during lean burn operation.

The new BF90 exhaust gas emissions conform to final year (2008) requirements stipulated under the CARB marine emissions regulations, with the motor achieving an ULTRA-LOW emissions rating. In addition, it also conforms to the European Recreational Craft Directive's stipulated values, in force since 2006.

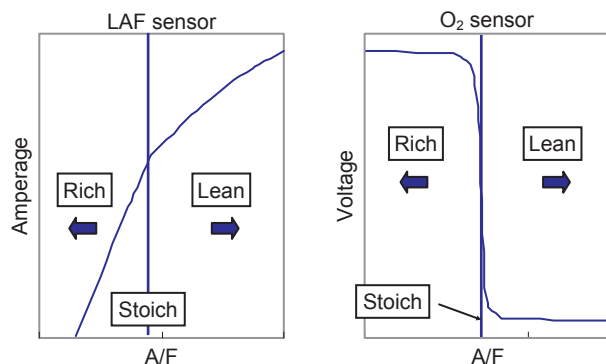


Fig. 5 A/F ratio sensor output

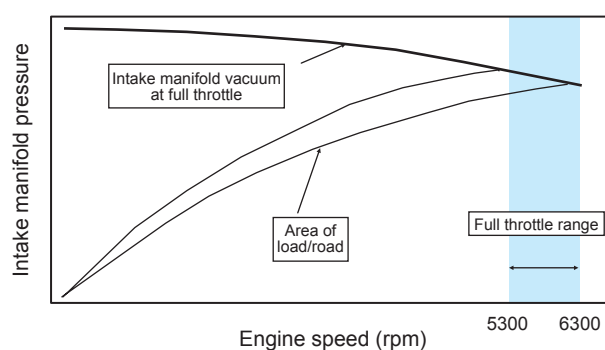


Fig. 6 Intake manifold pressure

4. Enhancing Operating Performance

4.1. Speed Increases due to Gear Case Shape Modifications

The underwater gear case parts comprise the gear box section, the parts connecting the gear box to the frame (body section hereafter), and an anti-ventilation plate provided to maintain pressure on the top of the propeller. Figure 7 shows the structure of the gear case. Making these parts smaller reduces the water resistance of the immersible parts, but ensuring the exhaust path and the durability of the gear need to be considered, and so making them extremely small is difficult. The following two items were the main focus when working to increase maximum speed both in the actual units and in simulations:

- (1) Modifications to the anti-ventilation plate, to reduce water resistance
- (2) Modifications to the gear box section and curve radius shape on the front of the body section, to enhance propeller aeration toughness by mitigating surface pressure reduction

The shape of the new BF90 gear case anti-ventilation plate was modified to make the case as small as possible compared to the current BF90 with no drop in aeration toughness when accelerating or under high load. This resulted in a maximum speed increase of approximately 0.8 km/h. In addition, a maximum speed increase of approximately 0.9 km/h was also achieved due to modifications to the water screen and screen rear shape, and tapering of the shape at the front and rear of the gear box section.

In comparison with the current BF90, a simulation of the pressure distribution on the surface of the new BF90 gear case showed mitigation of pressure reduction, due to enlargement of the gear box and front surface curve radius stop area. Figure 8 shows gear case surface pressure distribution. Changing the surface curve radius of the front of the body section from 250 mm to 500 mm leads to a speed increase of approximately 0.9 km/h. Figure 9

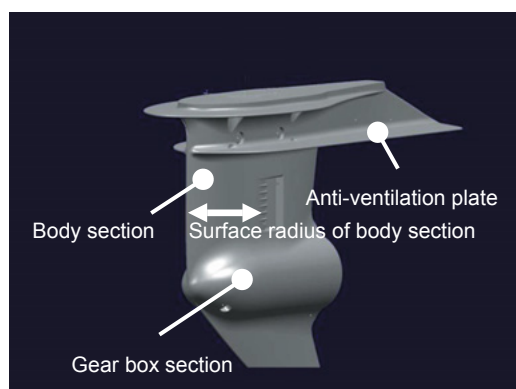


Fig. 7 Structure of gear case

shows the maximum speed according to differences in the front surface curve radius of the body section. These gear case shape modifications provided a maximum speed increase of 2.6 km/h over the current BF90.

4.2. Technologies to Reduce Weight

Through the use of a neodymium magnet ACG and by integrating the exhaust manifold into the cylinder head, the dry weight has been reduced by 7 kg compared to the current BF90.

4.2.1. Neodymium magnet ACG

To achieve a lightweight and compact unit that also has high charge power, the new BF90 uses a neodymium magnet ACG that is attached to the crankshaft instead of the belt driven alternators that are fitted on the large FI Honda outboard motors (115 hp or more).

Compared to the conventional belt-driven alternator's charge system, this ACG weighs 20% less. Also, the total number of parts has been dramatically reduced by eliminating the belt drive mechanism.

Moreover, by having the ACG stator coils and rotor closely attached to the engine, the height was reduced by approximately 10% as compared to conventional multi-pole magnet ACGs. To adapt the neodymium magnet ACG for use in an outboard motor environment, an air intake port was added to the ACG rotor, creating a structure that cools the ACG stator coils and rotor magnet. In addition, when considering its use at sea, the

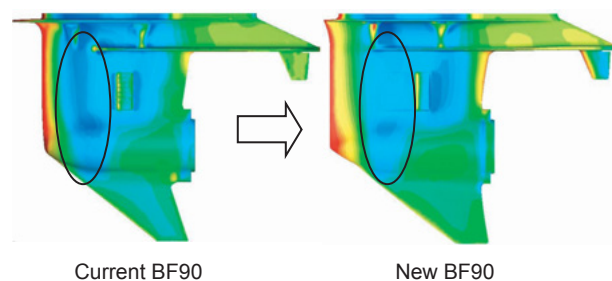


Fig. 8 Pressure distribution of gear case

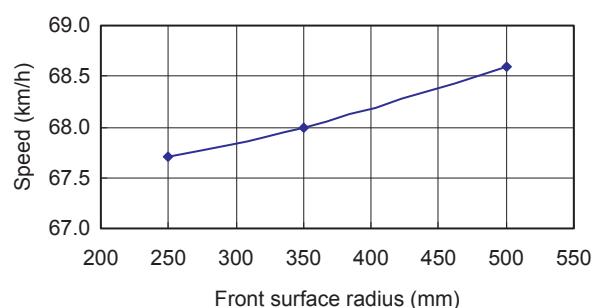


Fig. 9 Maximum speed according to front surface radius

specifications fully consider the corrosion resistance of the neodymium magnet. Figure 10 shows a photograph of the ACG.



Fig. 10 New BF90 ACG

4.2.2. Cylinder head with integrated exhaust manifold

Conventionally, the structure around the exhaust pipe is of two types – a separately fitted exhaust manifold, or a passage in the cylinder block. In contrast, the new BF90 creates an exhaust manifold using the cylinder head alone, thereby reducing the weight of the unit by 3 kg when compared to the conventional unit.

With this new cylinder head design, a dual independent circuit-control cooling system, water-cooled regulator, and cooling routes free from external pipes were also used, thereby achieving both high power and compact size.

Figure 12 shows the cooling routes.

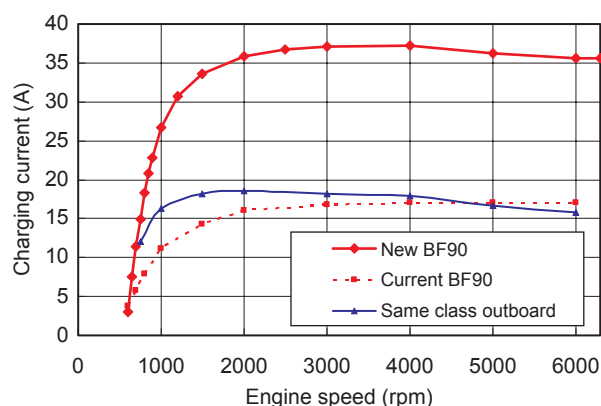


Fig. 11 Comparison of charging performance

4.2.3. ECU

The ECU, developed specifically for this new BF90, uses an Interstitial Via Hole (IVH) 4-layer circuit board to enhance density. The effective circuit connection surface area is increased by the use of non-penetrated inner via. By having circuitry pat on the via, the circuit board surface area was reduced by 45%. In combination with space-saving connectors, the case was made smaller, thereby reducing the injected resin reinforcements, making the weight of the ECU parts at least 40% lighter than ECU parts for the BF150's conventional in-line 4-cylinder engine. Figure 13 shows a photograph of the ECUs.

The engine control system was fitted with programmed fuel injection (FI) developed for outboard motors larger than the BF115. With the aim of achieving both excellent fuel economy and superior emissions performance, oxygen sensors and resonance knock sensors were adopted, the latter to detect engine knocking.

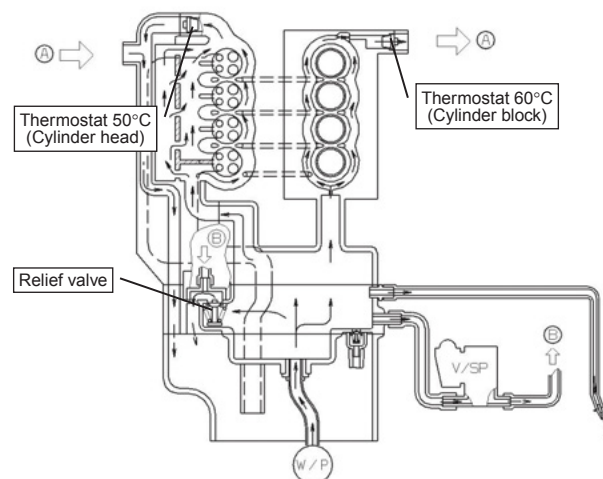


Fig. 12 Cooling system of new BF90

5. Conclusion

In the development of the new BF90, efforts were made to achieve both excellent fuel economy and superior operating performance. The following results were achieved, in comparison with the current BF90.

- (1) A 13% higher specific power.
- (2) A 20% enhancement in fuel economy.
- (3) In terms of acceleration performance, 0 to 200 m acceleration was reduced by 0.9 sec.
- (4) A 4.6 km/h higher maximum speed.

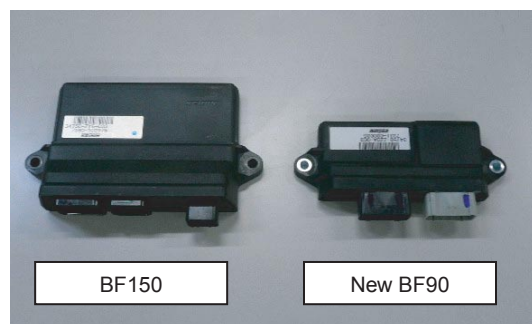


Fig. 13 New BF90 ECU

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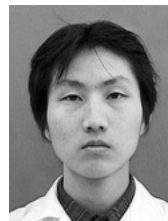
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