

Development of High-power, High Fuel Economy BF150 Outboard Motor

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ABSTRACT

Honda has developed a 4-stroke (4st) 110 kW (150 hp) engine for the highly popular 150 hp class of the outboard engine market. A variety of technologies have been employed to increase power and reduce weight to produce a 4st engine in a horsepower class normally associated with 2-stroke (2st) engines and equal the performance of competitors' 2st engines.

To increase the power of the engine, automotive engine technologies including DOHC-VTEC were employed, together with a dual control cooling system (unique to outboard motors) and a variable intake port system utilizing butterfly valves. Improved performance was achieved through the application of weight saving technologies including a resin engine undercover manufactured using a new production process and a new oil case structure and the employment of a gear case that lowers the gear ratio to cope with the demands of the large propeller.

Increased fuel efficiency was achieved through the employment of lean-burn using linear air/fuel ratio (LAF) sensor control in a world first for an outboard motor.

As a result of the technologies outlined above, a 15% increase in specific power (kW/L) was achieved in the new outboard versus previous Honda models. The motor satisfies the emission requirements stipulated in the 2008 CARB regulations while increasing fuel efficiency by 20% versus the previous model in the same output range, and offers an excellent balance between running performance and fuel economy. In actual offshore use, the top speed and acceleration of the new outboard match those of competitors' 2st engines.

1. Introduction

Large-class outboard motors (74 kW [100 hp] and over) account for approximately 22% of all outboard motors in use around the world (FY2000; Honda research), and the total number is approximately 144 000 units.

Honda first marketed a model in this class in 1998, with

the BF130/115⁽¹⁾. The company continued its production of engines in the class with the BF225/200⁽²⁾ in 2001, and the BF175, a detuned BF200, in 2002.

Sales of engines in this class are increasing with the general expansion of the total market for outboard motors. Against this background, the market demand for engines in the output class between 110 kW and 147 kW

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(150 hp-200 hp) has increased rapidly as a result of their excellent fuel economy and ease of use and increased environmental consciousness among users. However, at present, outboards fitted with 2-stroke direct-injection engines (2st DI) have the strongest commercial appeal from the perspective of fuel economy, and make up close to half the market share in the class. For Honda to really compete in this class it was essential not only to produce an outboard that bettered the economy and environmental performance of other motors on the market, but to employ technologies giving the motor a market-leading fuel economy and a low weight and level of power output equal to competitors' 2st outboards while maintaining the high reliability of a normal 4st outboard.

2. Development Goals

The target in the development process was the achievement of a superb balance between running performance and fuel economy. Specifically, this meant the achievement of the top level of specific power (kW/L) for a 4st outboard motor, and the top level of fuel economy for any outboard motor.

The achievement of these targets would involve employing;

- DOHC-VTEC
- A resin variable intake manifold
- A dual controlled cooling system (A first for an outboard motor) to increase engine power.

The improvement of running performance would involve;

- Reduction of the weight of the outboard (Target: lower weight than the BF130)
- Employment of a gear case designed for use with a large propeller.

Fuel economy was improved through the achievement of;

- Lean-burn employing an LAF sensor control (a first for an outboard motor).

In addition, the new outboard was provided with the various alert control mechanisms employed in the flagship of the Honda outboard range, the BF225, and the use of stainless steel in the bracket system components was increased, as part of efforts to enhance the commercial appeal of the motor through the achievement of class-topping reliability and thorough consideration of ease of operation and maintenance.

As indicated above, the BF150 was developed to be the top of its class in running performance, fuel economy, reliability, and handling, in fact in every aspect of outboard performance.

The external design of the new outboard is based on the integrated lines of the Wing Form which was extremely well received in the market when employed in the BF225, and the motor strongly reflects the high level of advancement of Honda outboards. Figure 1 shows an external view of the BF150.

3. Main Specifications and Overview

The main specifications of the BF150 are shown in Table 1.

The engine shares the main drive components, including the crankshaft and connecting rods, with the 2.4L in-line 4-cylinder engine employed in the 2003 US Accord. A 4-valve DOHC system, which features a 3-rocker arm VTEC mechanism on the intake side only, was employed for the valve system. To modify the engine for use in an outboard motor and enable it to be positioned vertically, the lubrication and cooling systems utilized in the automotive engine were extensively redesigned, based on knowledge obtained from the development of the BF130. The BF150 employs the automotive cylinder head used in the BF225, meaning that no special facilities are required for the production of a cylinder head exclusively designed for this outboard, thereby lowering production costs. The dimensions of the engine cover were established on the basis of considerations of interchangeability of installation with competitors' 2st motors. The total width was set to enable the pitch with two motors mounted to be compatible with that of already available 26-inch (660 mm) models.

To enable the outboard to be used on high-speed boats, the transom height was reduced by 29 mm against the BF130, and the water screen was positioned lower, ensuring that the motor is able to take in a sufficient amount of cooling water even when trimming up and planing.

Ease of handling was a serious consideration in the design of the new outboard, therefore the BF150 was fitted with a small engine cover, a rear grommet was provided to enable minor adjustments and the maintenance points were concentrated on the starboard side, enabling ease of maintenance. A polypropylene injection-molded undercover was employed to reduce the weight of the motor. A new structure was used in the undercover, designed to ensure rigidity and enable the number of components to be reduced. The number of link components in the shift mechanism was reduced against the previous model, improving the shift feel.



Fig. 1 External view of BF150

Table 1 BF150 L-type Specifications

Overall length (mm)	845
Overall width (mm)	580
Overall height (mm)	1 665
Transom height (mm)	508
Dry weight (kg)	217
Engine type	4stroke L-type 4 cylinder
Displacement (cm ³)	2 354
Bore (mm) × stroke (mm)	87 × 99
Compression ratio	9.6 : 1
Valve train	DOHC-VTEC 16 valves
Number of valves	4/cylinder
Maximum power (kW/rpm)	110 / 5 500 (150 PS / 5 500 rpm)
Maximum torque (N·m)	202
Recommended engine rpm range	5 000 - 6 000
Fuel supply system	Programmed Fuel Injection
Ignition system	Programmed Ignition (with Plug Hole Coil)
Charge output (A)	40
Cooling system	Water cooling (with 2 thermostats)
Exhaust system	Through propeller hub

The LAF sensor employed to achieve lean-burn is based on the model utilized in automotive applications, but was altered to enable it to be fitted directly to the exhaust manifold and to increase its toughness with regard to water immersion from the exhaust pipe. The newly developed ECU employs the various alert mechanisms utilized in the BF225, and is based on an automotive program, but utilizes special settings for an outboard motor.

4. Component Technologies

4.1. Technologies Employed to Increase Engine Power

4.1.1. Dual controlled cooling system

The BF150, in a first for an outboard motor engine, was provided with independent cooling systems for the head and the block, increasing both the knock limit and the power output of the motor.

In a normal engine, the cylinder head and cylinder block water jackets are connected by the gasket face, and one thermostat is employed to control water temperature.

However, when an outboard employing this conventional system directly takes in sea water, etc., for cooling, excessive cooling on the cylinder block side may cause oil dilution. Therefore, it is not practical to lower the set water temperature in the control system below a fixed point. This prevents more effective cooling being provided to the cylinder head side, which represents an obstacle to increasing power.

In the BF150, therefore, the head gasket was used to completely separate the cooling water routes for the cylinder head and the cylinder block, making them entirely independent. Two thermostats are used to provide separate water temperature control for each route. This means it was

possible to make the control temperature for the thermostat on the cylinder head side (50 °C) lower than the control temperature on the block side (60 °C), leading to an increase of approximately 8° in the knock limit and approximately 2.5% in engine power.

In addition, the exhaust manifold and oil gallery are cooled by cooling water routes which are divided from the cylinder head and block routes. Figure 2 shows a diagram of the cooling water routes in the BF150.

4.1.2. Resin variable intake manifold

To balance high torque at low and medium engine speeds with high power at high engine speeds while at the same time as reducing weight and increasing corrosion resistance, an all-resin variable intake manifold was employed in the BF150.

The variable intake port system in the BF150 employs butterfly valves to vary the length of the intake pipe in two stages. The effect of this system is multiplied through its employment in combination with VTEC, enabling the outboard to display both flat torque from low to high engine speeds and high power. Figure 3 shows an outline of the variable intake port system, and Fig. 4 shows a graph of the power curve of the BF150.

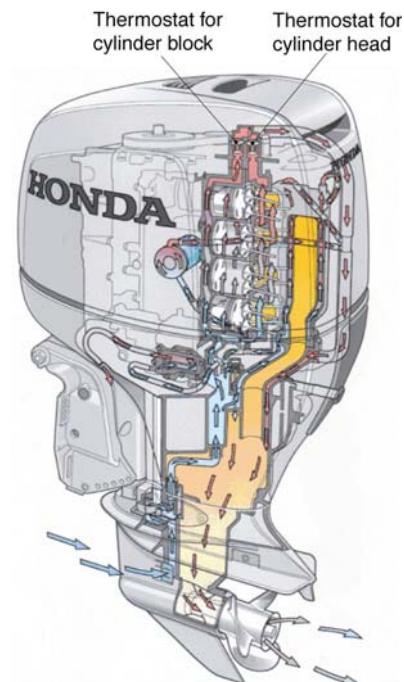


Fig. 2 Dual control cooling system

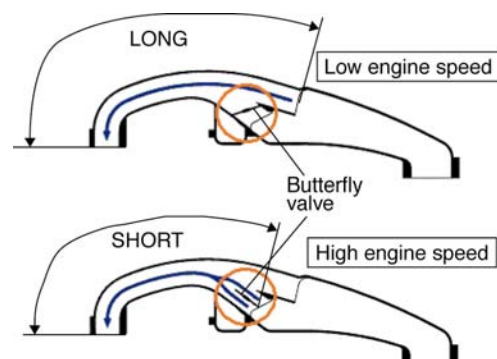


Fig. 3 Variable air intake port system

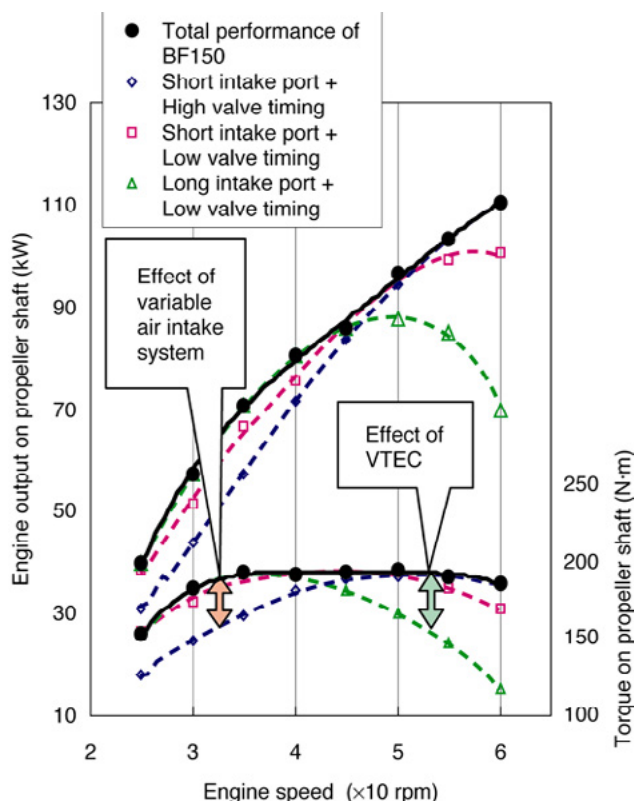


Fig. 4 Power curve of BF150

The number of component parts was reduced by integrating the vacuum tank used to operate the valves, the diaphragm body and the check valves with the main body. In combination with the use of resin materials, this reduced the weight and increased corrosion resistance. The butterfly valves that enable switching between intake lengths were also made of all-resin, with resin materials employed in the main body and the bearings. This reduced the weight by 2.7 kg against the aluminum die cast model. Figure 5 shows a cutaway view of the variable intake system.

The technologies described above were employed to increase the power of the motor, and enabled specific power (kW/L) to be increased by 15% against the BF130, and gave the motor the highest specific power of any 4st outboard. Figure 6 shows a graph comparing the specific power of the BF150 with other models.

reduce the number of components in the support structure. The employment of this structure reduced the weight by 1 kg. Figure 7 shows the structure of the engine undercover.

(2) Oil case structure

In conventional oil case structures, the oil pan is covered by the extension case with the exhaust pipe mount on it and cooling water flows inside the case in the form of a shower to reduce transmitted noise from the exhaust. In an effort to achieve significant weight reductions in the BF150, the oil pan and exhaust pipe were integrated, and the oil case was integrated with the upper section of the extension case. The exhaust pipe is positioned in the approximate center of the oil case. In addition to ensuring that the exhaust outlet is located at a sufficient distance from the external cover, this structure

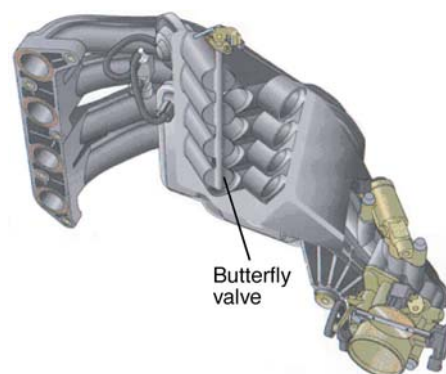


Fig. 5 Cutaway view of intake manifold

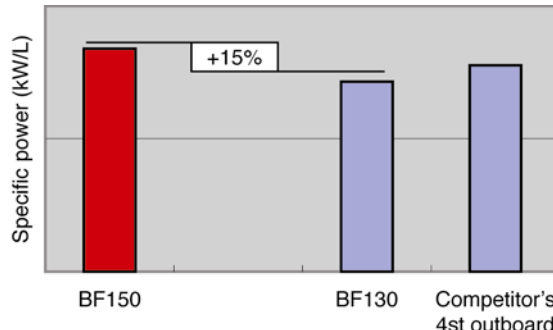


Fig. 6 Comparison of specific power

4.2. Technologies Employed to Improve Running Performance

4.2.1. Weight reduction technologies

To reduce weight, in addition to the resin variable intake manifold, a lightweight resin engine undercover manufactured using a new production process was employed, and the oil case was integrated with the upper section of the extension case.

(1) Lightweight resin engine undercover (manufactured using new production process)

When a resin engine undercover is employed in a conventional outboard, metal components are used to reinforce the interior to prevent deformation of the cover when the motor is being carried horizontally. In the BF150, a blow-molded internal frame is welded to the interior of an injection-molded external cover in order to lower weight and

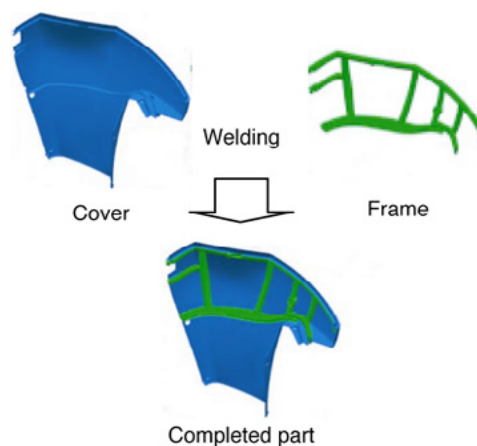


Fig. 7 New product engine undercover

divides the interior of the oil case by means of the oil pan, minimizing the resonating internal surface area and suppressing transmitted noise from the exhaust. The new structure also reduced the weight by 2 kg. Figure 8 shows a cutaway view of the oil case structure.

4.2.2 Redesign of the drive system

The gear case of the new outboard was redesigned to enable weight to be reduced in spite of the increased diameter of the housing required for the large diameter propeller, formerly used in the BF225.

To match the gears with the large diameter propeller, the gear ratio was lowered, and the gears were increased in diameter in accordance with the increased diameter of the housing, thereby increasing durability. As a result, the BF150 equaled the top speed and acceleration time over 200 m from a standstill of a competitor's 2st DI outboard in the same class.

Figures 9 and 10 show comparisons of the top speed and acceleration time of the BF150 with a competitor's 2st DI respectively.

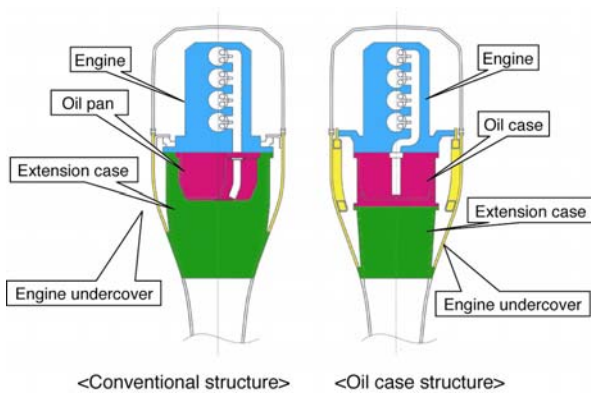


Fig. 8 Cutaway view of oil case

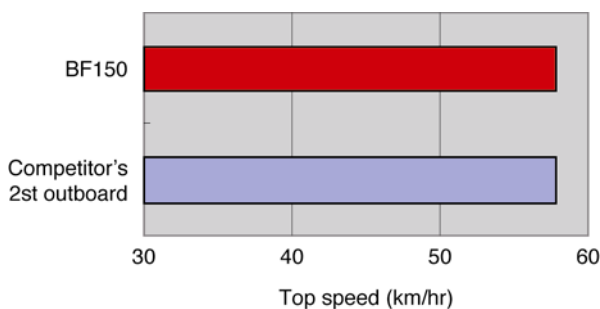


Fig. 9 Top speed

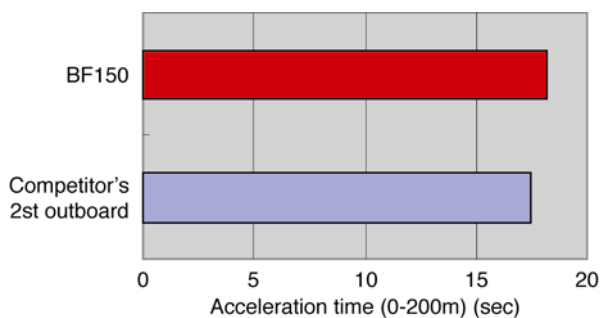


Fig. 10 Acceleration performance

4.3. Technologies Employed to Increase Fuel Economy

4.3.1. Achievement of high fuel economy with lean-burn

PGM-FI is used in the intake and fuel systems of the BF150 to enable the motor to both meet a variety of international exhaust emissions regulations and significantly exceed the fuel economy performance of competitors' outboard motors. In addition, lean-burn control using LAF sensors was utilized for the first time in an outboard motor. As a result, the fuel consumption of the BF150 in emission measurement mode is 20% lower than the Honda BF130 and 15% lower than a competitor's 2st DI outboard with the same power rating. A comparison of fuel consumption is shown in Fig. 11.

For users to clearly recognize how good the fuel economy of an outboard motor is, it is essential for the motor to display excellent fuel economy at cruising speeds, which are used most frequently. The BF150 employs lean-burn up to an engine speed of 4 700 rpm, enabling users to be aware of its excellent fuel economy when used with any watercraft.

The air-fuel ratio for lean-burn was set at $A/F = 18$ to achieve a balance between fuel economy and drivability. To control sudden increases in power output when the motor goes from a lean to a rich ratio, the BF150 was provided with a throttle cam with a nonlinear opening characteristic ensuring excellent output control.

Figure 12 shows the effect of lean-burn in reducing fuel consumption in use on a standard boat, and Fig. 13 shows the lean-burn area. The throttle body is shown in Fig. 14.

The BF150 cleared the final year (2008) values for the CARB marine emissions regulations, and achieved an ULTRA-LOW emissions rating. The motor also passed in advance the emissions regulations that go into effect in the EU in 2006. Figures 15 and 16 show the emissions levels achieved by the BF150.

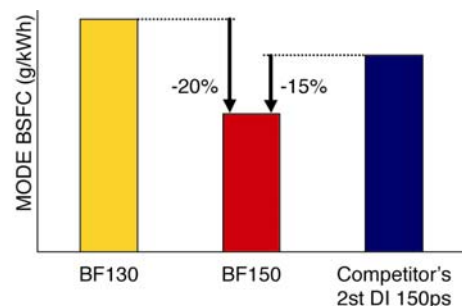


Fig. 11 BSFC in emission measurement mode

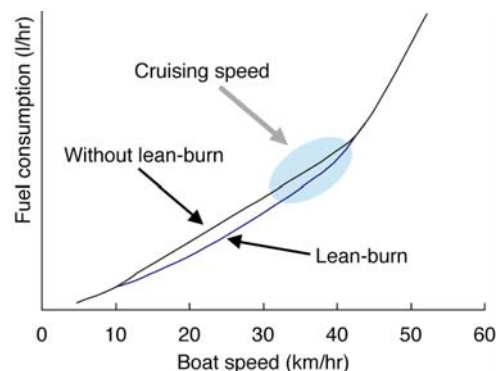


Fig. 12 Effect of lean-burn

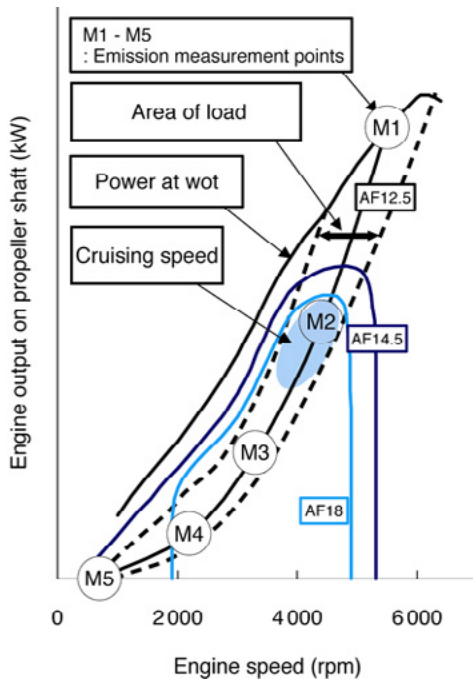


Fig. 13 BF150 lean-burn area

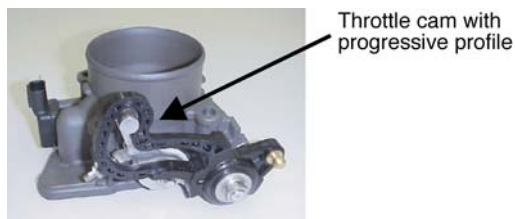


Fig. 14 Throttle body

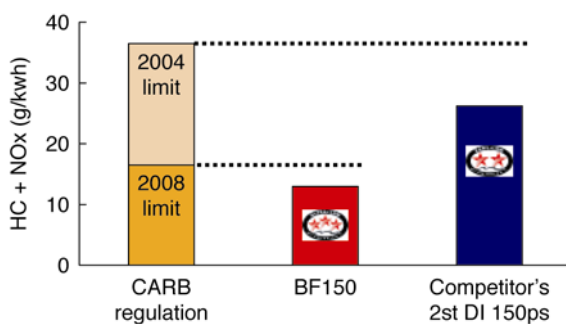


Fig. 15 Level of exhaust emissions (CARB)

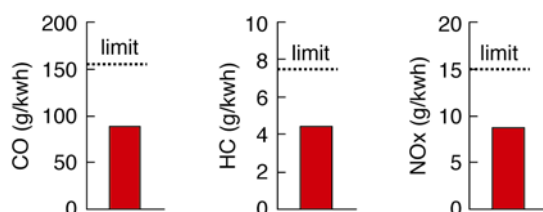


Fig. 16 Level of exhaust emissions (EC)

4.3.2. Adapting LAF sensor to outboard use

The LAF sensor employed in the BF150 was based on the model used in automotive applications, but was altered to fit the special conditions of use in an outboard. Specifically, it was modified to enable direct mounting on the exhaust manifold and to increase its resistance to taking in water from the exhaust pipe.

The vibration experienced by the LAF sensor when mounted directly on the exhaust manifold differs from the vibration experienced in an automotive application, and its internal structure was therefore modified.

Because the exhaust channel is in direct contact with sea water, the positioning of the LAF sensor on the exhaust outlet side meant that the unit would sometimes take in sea water. To minimize the amount of water coming into contact with the sensor elements, the sensor was therefore positioned against the upper edge of the exhaust manifold, corresponding to the topmost section of the exhaust channel flow path, and the shape of the sensor protector was redesigned.

4.4. Other Element Technologies Employed to Increase Commercial Appeal

4.4.1. Chain system for marine use

The BF150 is the first Honda outboard motor to employ a chain to drive the camshaft and balancer shaft.

The design of the system was based on the layout of an automotive engine, and aimed both to reduce the total height of the motor when mounted and to make the system maintenance-free through the use of an autotensioner.

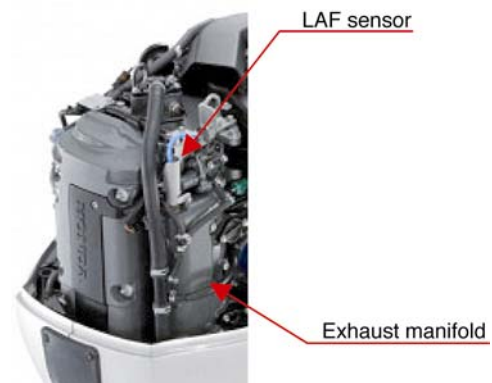


Fig. 17 LAF sensor layout

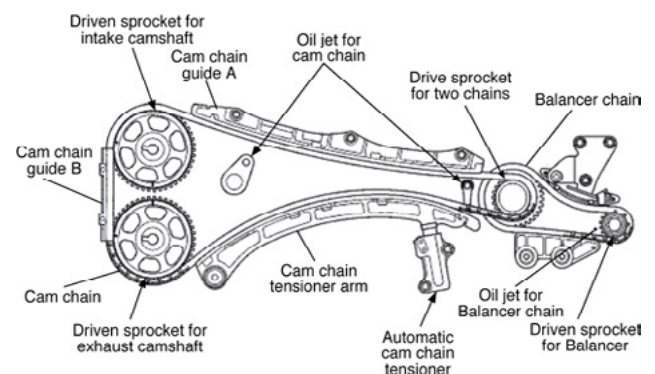


Fig. 18 Camshaft and balancer driving system

The system in the BF150 employs the same components as the automotive system, but the method of lubrication was changed for application in an outboard motor.

In the BF150, the crankshaft is perpendicular and the flywheel is positioned on the underside of the engine. The chain was therefore positioned in the topmost section of the engine. For this reason, if a standard automotive system was employed, in which the oil used to lubricate the cylinder head was then used to lubricate the chain, very little oil would be available to lubricate the chain.

To solve this situation, in addition to employing three new oil jets to provide lubricating oil, the shape of the area around the sprocket was redesigned to hold oil, and oil is directly provided to the chain. This ensures that a sufficient amount of oil is provided to lubricate the chain, helping prevent it from stretching and enabling the achievement of an equally high level of durability and reliability to that of the system employed in automotive engines. Figure 18 shows a diagram of the chain system.

4.4.2. Improvement of shift feel

The reduction of the number of links in the shift mechanism against the conventional structure reduced mechanical loss in the connecting sections and increased transmission efficiency, reducing the shift load and improving the smoothness of the shift feel. Figure 19 shows a diagram of the shift mechanism, and Fig. 20 shows a comparison of transmission efficiency under an operating load.

4.4.3. Improvement of ease of maintenance

The following structural modifications were made to increase ease of maintenance:

1) The oil level gauge, oil cap, oil filter and the oil drain and check bolts for the gear case were all positioned on the starboard side to offer ease of access.

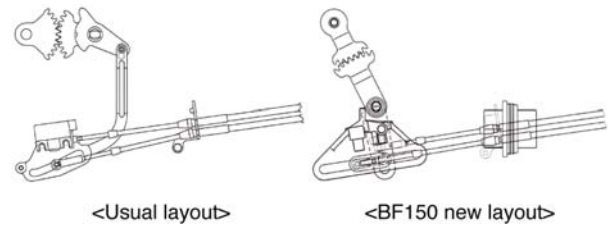


Fig. 19 Comparison of shift change system

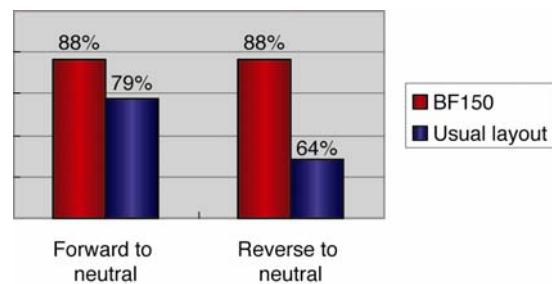


Fig. 20 Power efficiency of newly designed shift change system

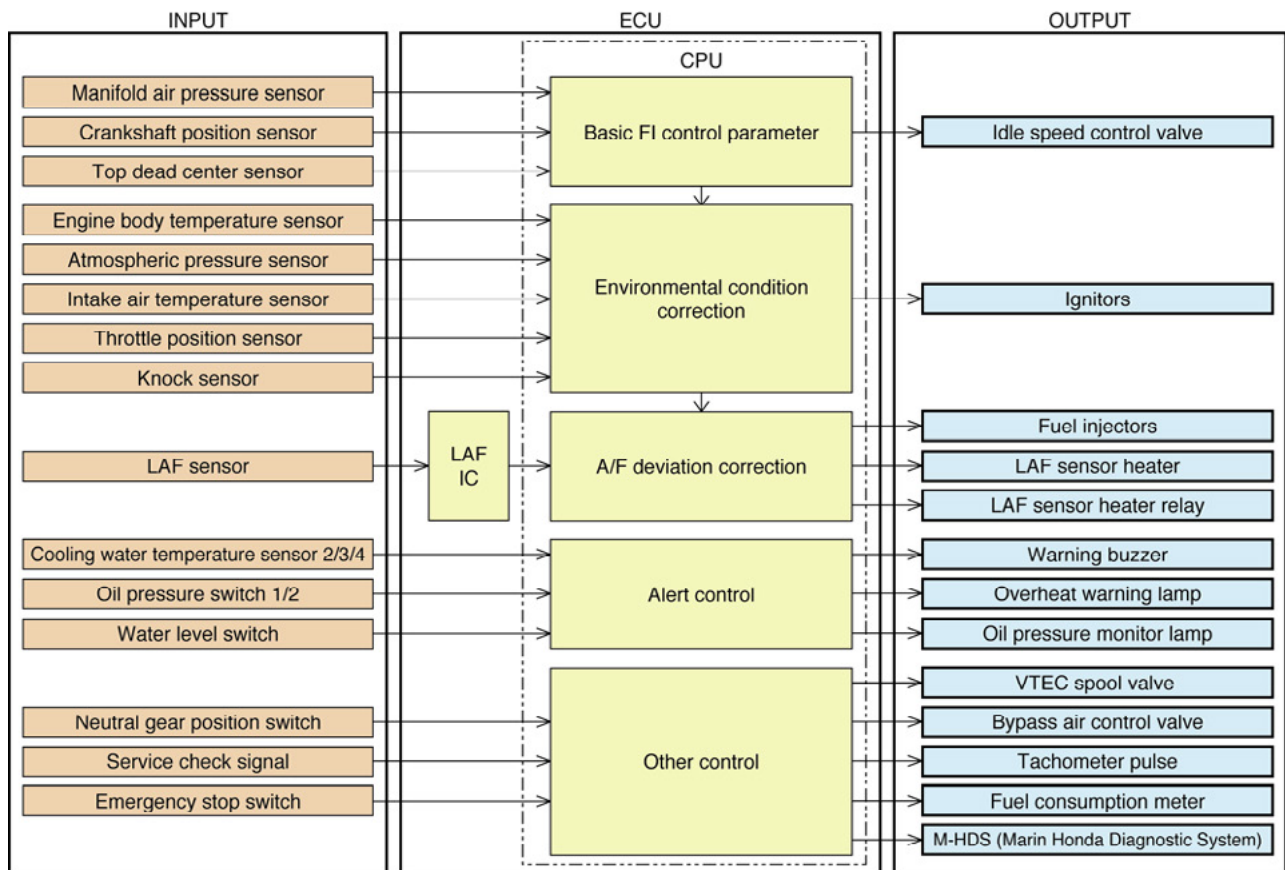


Fig.21 BF150 engine control system

- 2) The drain plug cover was placed in the engine undercover, which can be removed and replaced in one step, and can also be used to hold the drain oil.
- 3) The undercover grommet was placed in the rear of the engine cover so that it would be possible to inspect and clean the spark plug of the No. 4 cylinder without removing the engine undercover.
- 4) A two-part engine undercover was employed to increase ease of disassembly and reassembly.

4.4.4. Engine control system

(1) Overall system outline

The engine control system is based on an automotive system, but employs an LAF sensor to enable lean-burn for improvement of fuel economy and an alert system specifically designed for the usage of outboard motors, which has been used since the BF130 model. The utility of the system was increased through the use of digital meters and diagnostic mechanisms. Figure 21 shows a diagram of the control system.

(2) Alert and control systems

The following alert and control systems were employed to ensure that the BF150 has an equivalent level of reliability to the flagship model, the BF225.

1) Overheat alert

The cooling system of an outboard motor directly takes sea water, etc., into the engine. Matter floating on the surface of the water may therefore block the water inlets or the cooling routes, causing cooling performance to fluctuate. The cooling system of the BF150 employs a new structure, and overheat detection sensors were positioned at the cylinder head, the cylinder block and the exhaust manifold to accurately detect blockages in any of the cooling routes. This system helps ensure that an overheating alert is given if the temperature at any of these detection points increases over a predetermined level for each point. When overheating is detected, the algorithm cuts the fuel supply, stops the spark plug firing, and progressively reduces engine speed. If this does not correct the overheating, the system finally shuts down the engine. During this period, a buzzer and a warning light indicate the situation to the user.

2) Other alert systems

To help prevent oil pressure from becoming low when the user forgets to adequately fill the oil, the BF150 is provided with high and low oil pressure switches, as employed in the BF225/200. The system monitors oil pressure, and sounds an alert if the oil pressure is too low for a particular engine speed. Buzzers and warning lights also indicate malfunctions in the alternator as well as if there is water pooled in fuel tank, so as to help keep it from infiltrating into the fuel lines.

(3) Backlash detection and control system

Because an outboard motor has no brakes, there are times when the shift lever is suddenly changed from forward to reverse to avoid danger when the engine is running at high speed. When this happens, the momentum of the boat causes backlash in the engine through the propeller. The control system in the BF150 monitors changes in the angular velocity of the crankshaft and can detect the transition to backlash the instant it occurs, ensuring that the engine can be brought to a smooth stop without the adverse affects of backlash.

4.4.5. Utility

(1) Digital meters

There has recently been a high level of demand for digital meters to be offered as options on outboard motors, in order to provide the user with a higher quantity of more accurate

information and make that information easier to read. The BF150 is the first Honda outboard to employ digital meters. In addition to displays showing craft speed and engine speed, the motor has a fuel consumption display which accurately calculates the amount of fuel injected from the time required for injection. The digital meter is shown in Fig. 22.

(2) Diagnostic mechanism

As an aid to service and maintenance, as on Honda's other outboards, if a sensor failure or other malfunction is detected, buzzers and warning lights indicate the malfunction and the number of times the warning light flashes indicates where the malfunction is occurring. In addition, the system remembers the status of the control systems in the engine when the malfunction occurred, and the Marine Honda Diagnostic System (M-HDS) can be used to read it from the diagnostic communications port, enabling the malfunction to be easily located. The M-HDS is shown in Fig. 23.

5. Conclusion

The application of the component technologies described in Section 4 has resulted in the following improvements to the BF150 against the BF130:

- (1) Specific power (kW/L): 15% increase (Top level for a 4st outboard motor)
- (2) Mode fuel consumption: 20% decrease (Top level for an outboard motor; 15% decrease against competitor's 2st DI)
- (3) Total weight: 5 kg decrease (15% decrease in power-weight ratio)
- (4) In terms of running performance (in an offshore boat), the BF150 has an identical top speed and acceleration over 200 m as a 2st DI motor.



Fig. 22 Digital meter with fuel consumption gauge



Fig. 23 M-HDS

6. Afterword

The BF150 is a model that will play an extremely important role in establishing Honda's large class outboard motor lineup in the market, looking towards the expansion of the company's OEM business.

The adaptation and employment of existing automotive technologies and structures and the active development and application of new mechanisms and structures unique to outboard motors has given the new model a level of appeal not possessed by other outboards on the market, making it a highly commercially viable product.

The experience of creating the BF150 was an extremely valuable one for the design team. The new motor is an embodiment of their persistence in staying true to "Challenging Spirit," the mainstay of Honda's product development efforts, their active pursuit of their goals from the stage of proposal of product targets and the consistency of their methods of achieving those targets from the initial stages of design.

This development received generous assistance from numerous individuals from Honda and other companies, including staff members of a number of manufacturing centers. In particular, it was of tremendous help to receive direct advice concerning the adaptation of the automotive engine to an outboard motor application from the team which developed the engine⁽³⁾. The authors wish to take this opportunity to once again offer their sincere thanks to everyone who assisted in this project.

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