

Development of Honda Flagship Outboard Motor “BF225/200”

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ABSTRACT

Honda has developed 225 and 200-horsepower outboard motors powered by a 3.5-liter V-type 6-cylinder (V6) engine, the largest such outboard motors in the world, as the flagship models in its 4-stroke outboard motor series. The BF225/200 models are the first 4-stroke outboard motors to use the VTEC (variable valve timing and lift electronic control system), a variable intake and O₂ feedback system. The resulting engine performance also makes them the world's first outboard motors in the 200-hp class to achieve emissions levels that satisfy the year 2008 values for marine engine exhaust emissions set by the California Air Resources Board (CARB). At the same time, they have achieved a highly balanced performance improvement, with a maximum torque that is 10% greater and fuel consumption that is approximately 15% lower than previous models. The adoption of non-chrome coating methods for exterior parts on these motors has achieved the environmental compliance while maintaining coating quality on a par with previous models. In terms of comfort, their low vibration and low noise place them at the top of their class. The out bank exhaust manifold design with the same construction as V6 automotive engines and the use of a plastic inlet manifold makes these models lightweight and compact enough to replace conventional 2-stroke outboard motors without requiring any modification to the boat. Honda has achieved these performance levels while maintaining high reliability and simultaneously reducing cost by standardization of basic specifications and communizing parts with its automotive V6 engines.

1. Introduction

The US represents the largest market for outboard motors in the world. From 2001, California Air Resources Board (CARB) emissions regulations were instituted in the US alongside the existing Environmental Protection Agency (EPA) regulations. In addition to the importance of complying with the CARB 2008 regulations, another factor

influencing the design of outboard motors is the move away from conventional two-stroke motors and the rapidly increasing demand for four-stroke motors with clean emissions, high fuel economy, and low levels of noise and vibration.

Honda has engaged in continuous production of four-stroke outboard motors exclusively since 1964. In 1998, the company announced the development of the BF130/115⁽¹⁾, a

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motor with the highest horsepower of any four-stroke outboard motor at that time. Honda has now developed the BF225/220, shown in Fig. 1, to complete its full line-up of outboard motors, and to increase its competitiveness in the U.S. market, the main market for large outboard motors, accounting for 80% of yearly world unit sales.



Fig. 1 External view of BF225

2. Aims of the Development

The BF225/200 maintains the commitment of Honda's outboard motor series to user friendly and environmentally friendlier four-stroke motors of the highest quality at an economical price. In addition, the new model represents a world first in featuring the following new technologies for the first time in an outboard motor:

- Variable valve timing and lift electronic control (VTEC)⁽²⁾
- A variable intake system
- External non-chrome finish

It also features the following technologies for the first time in a four-stroke outboard motor:

- An O₂ feedback system
- A knock control system

The new outboard motor has the highest horsepower in the Honda series, and is friendlier to the environment and more economical and reliable than competitors' two-stroke direct injection (2stDI) outboards or existing four-stroke outboards. It was developed with the aim of creating Honda's flagship outboard motor, the leader of the next generation.

The development also aimed to minimize the effect of the larger engine cover necessitated by the four-stroke's more extensive valve system, and to create a package size and weight enabling the outboard to be fitted to a boat capable of fitting a comparable two-stroke motor without modification.

3. Main Specifications and Outline

Table 1 shows the main specifications of the BF225, and Fig. 2 shows a cutaway view of the newly developed outboard. The motor shares the components of its main dynamic system (crankshaft, connecting rods, etc.) with a 3.5-liter 60° V6 engine.⁽³⁾ In the interests of compactness, components from an SOHC-VTEC engine have been used for the valve system. Lubrication and cooling systems have been modified to allow utilization in a vertically mounted

Table 1 Specification

Code name	BF225 X-type
Overall length (mm)	920
Overall width (mm)	625
Overall height (mm)	1 800
Transom height (mm)	635
Dry weight (kg)	272
Engine type	4 stroke 60° V-type 6 cylinder
Displacement (cc)	3 471
Bore (mm) × stroke (mm)	89 × 93
Compression ratio	9.4 : 1
Valve train	SOHC VTEC 24 valves
Valve number	4/cylinder
Maximum power (kW/rpm)	165 / 5 500 (225 hp / 5 500 rpm)
Maximum torque (N·m)	295
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)	60
Cooling system	Water cooling (with 2 thermostats)
Exhaust system	Through propeller hub

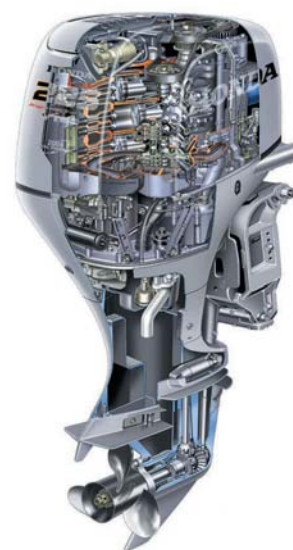


Fig. 2 Cutaway view of BF225

configuration. The oil filter and alternator have been located in the front of the engine as viewed from the direction of motion. The intake and fuel systems are located in the in bank at the rear of the engine, and the exhaust system is in the out bank. The ECU is located on the starboard side of the motor, with the starter on the port. This configuration gives the new outboard a slim external appearance.

The engine is the first four-stroke outboard motor engine to have VTEC, a variable intake and O₂ feedback system with knock control system. The engine follows previous models in featuring programmed fuel injection (PGM-FI), but represents an improvement in power, maneuverability, fuel economy and exhaust emissions over previous models. The control system is based on a proven automotive engine system. The alert system and other systems have been modified to match the characteristic functions and use requirements of an outboard motor.

4. Component Technologies

4.1 Use of Automotive Engine Components

Fig. 3 shows the relation between Honda automobiles and outboard motors. After having shared crankshaft and connecting rods of an automotive engine with the BF90/75, Honda went on to increase the number of parts shared in the BF130/115, which included an automotive valve train system and balancer mechanism. In addition to further increasing the amount of shared parts, the development of the BF225/200 also focused on sharing automotive production facilities for the cylinder block and cylinder heads, and thus adopted an engine layout different from that of previous outboard motors.

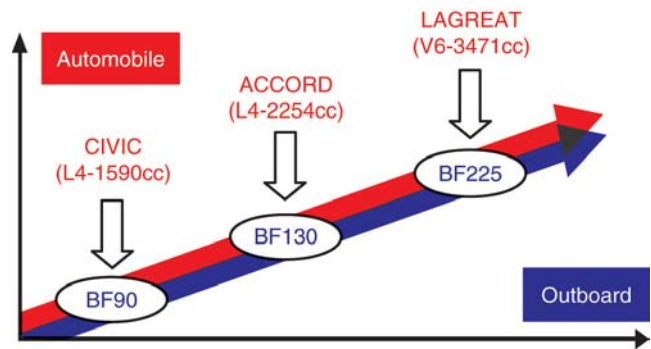


Fig. 3 Relation of automobile and outboard engine

Previous layouts have integrated the exhaust passage with the cylinder heads and cylinder block, in a configuration unique to outboard motors. To enable the BF225/200 components to share a mechanical processing line with automotive cylinder heads and cylinder blocks, the exhaust passage has been separated from these components, and has the same dimensions as an automotive engine. A full jacket has been adopted for the periphery of the exhaust port. The separate exhaust passage is composed of an exhaust guide supported by a water-cooled aluminum exhaust manifold fixed to the head and mount case. Exhaust gas from the head does not pass through the cylinder block, but is guided directly to the extension case below the mount case. This configuration has made it possible to utilize the same head gasket as an automotive engine. The crankshaft is supported by sintered alloy bearing caps of the type used in automotive engines. By these means high reliability has been balanced with cost reductions in the new outboard. Fig. 4 compares the structure of the power head in the new motor with a previous motor.

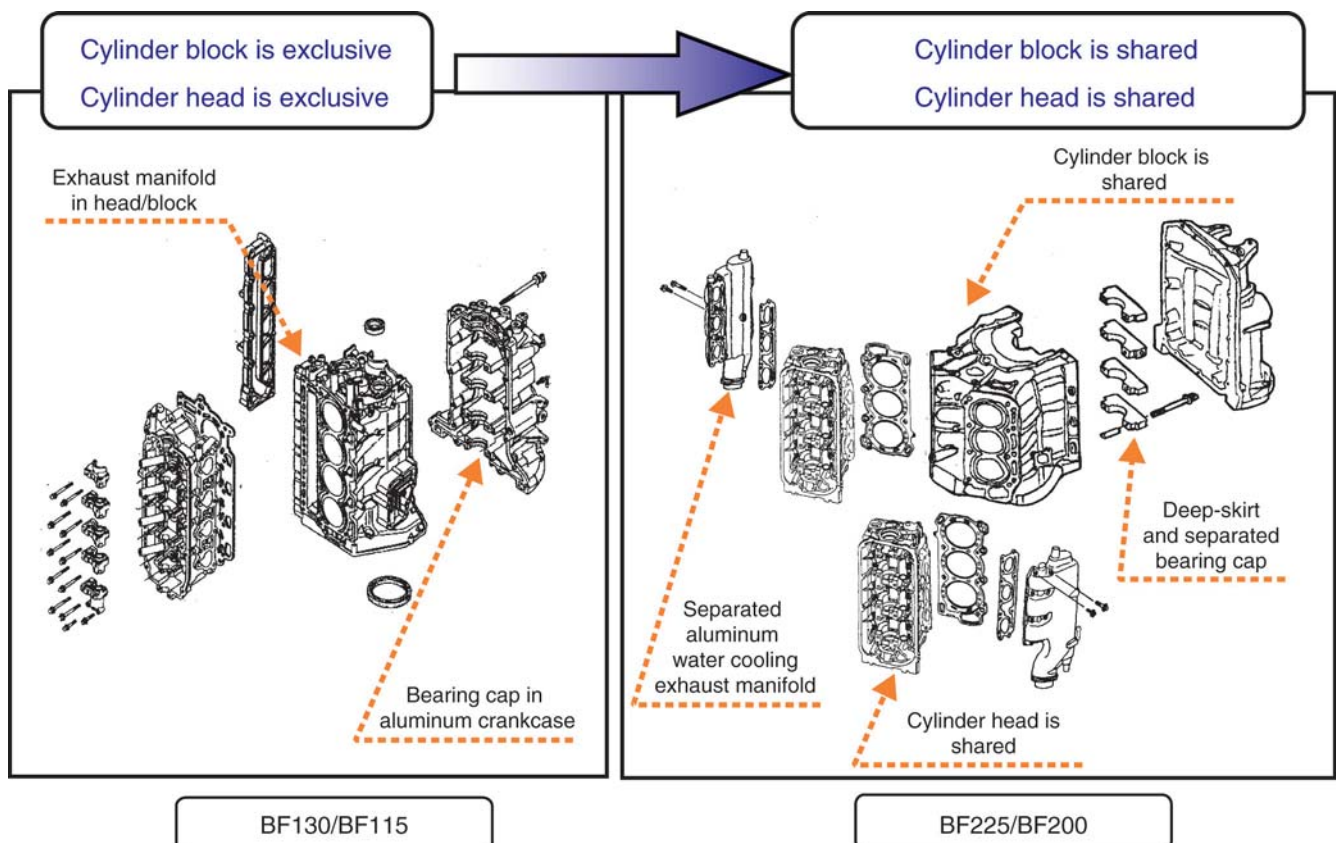


Fig. 4 Structure of power head

4.2 VTEC/Variable Intake System

The displacement of the BF225 was established with the output power of the BF200 as a base. The BF225 is the first outboard motor engine to utilize VTEC, which has resulted in the increased output power.

The VTEC system used in the BF225 is variable only on the intake side, and the high-speed valve timing setting enables maximum output at 225 horsepower. Valve timing settings at low to medium speeds were established with consideration of idling stability and ease of use in the normal operating range of the engine. Adoption of the variable intake system has increased low to medium speed torque. By opening and closing the valve separating the right and left chambers of the intake manifold, the variable intake system is able to use resonance effects below 4,000 rpm and inertia effects above 4,000 rpm, increasing the volumetric efficiency. This valve is located inside the aluminum upper cover on the back surface of the inlet manifold chamber.

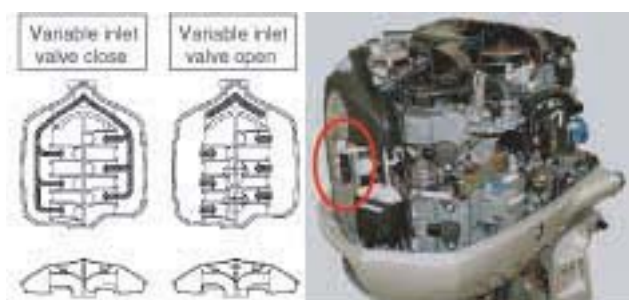


Fig. 5 Variable inlet valve

Fig. 5 shows a conceptual diagram and a cross-sectional view of the variable inlet valve, and Fig. 6 is a graph of the output characteristics of the BF225.

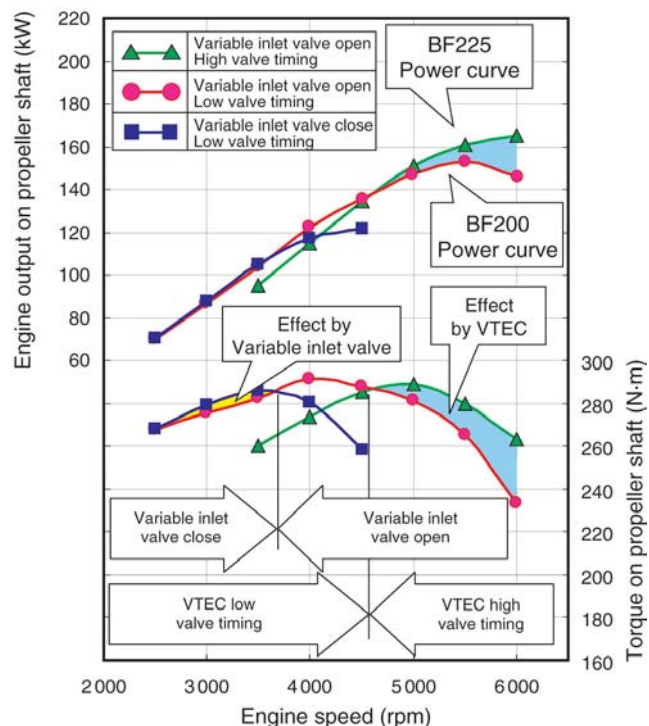


Fig. 6 Power curve of BF225/200

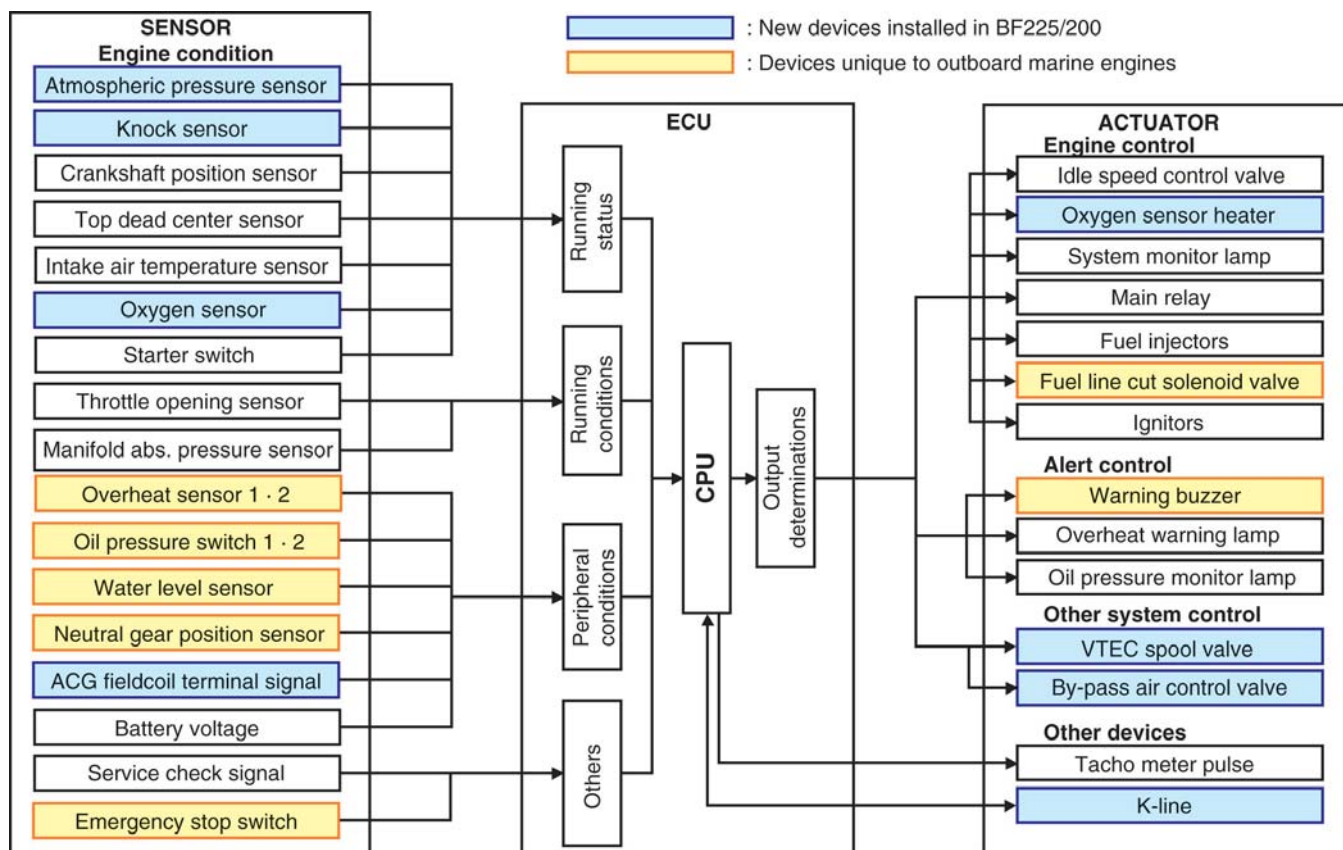


Fig. 7 BF225/200 Engine control system

4.3 Engine Control System

4.3.1 Total system outline

Honda's previous outboard motor, the BF130/115, was its first to be provided with PGM-FI, and the resulting ease of starting and reliability became an important selling point. Basic performance of the BF225/200 has been taken to a still higher level, as befits the flagship of Honda's Outboard series. It features an O₂ feedback system to increase fuel economy and decrease exhaust emissions; a knock control system to increase power; and improved alert control systems (overheating, oil pressure, PGM-FI, ACG, water separator alert) to increase reliability. The systems are based on automotive control systems, but the alert systems were newly designed with consideration of the requirements for outboard motor use. The heat, vibration, corrosion and water immersion resistance of each component has also been increased on the basis of the same considerations. Fig. 7 shows a diagram of the engine control system.

4.3.2 O₂ feedback system

To balance high fuel economy and low exhaust emissions, the new engine has been provided with PGM-FI for the intake and fuel systems and, an O₂ feedback system was adopted for the first time in a four-stroke outboard motor. These systems have enabled the achievement of an 8% decrease in fuel consumption against our competitors' 2stDI outboard motors of the same power. The engine has cleared the CARB marine engine (2008) exhaust emissions standards, becoming the first 200 horsepower class outboard motor to achieve an ULTRA-LOW emissions level. Fig. 8 shows BSFC figures, and Fig. 9 shows exhaust emission levels.

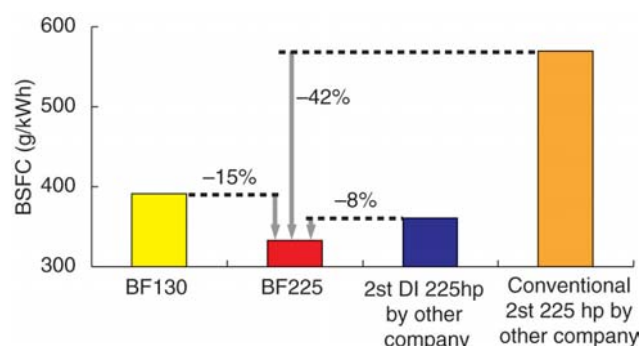


Fig. 8 BSFC on the emission-measuring mode

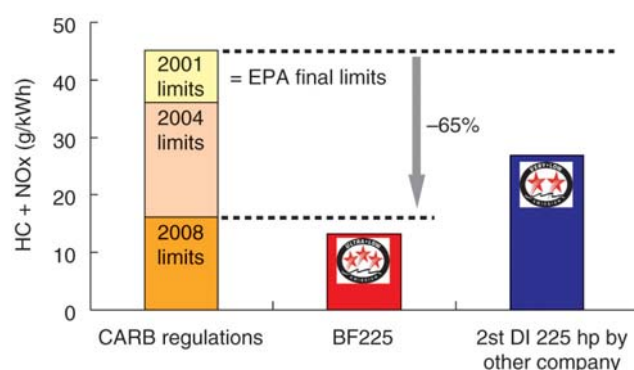


Fig. 9 Exhaust emissions comparison

When an outboard motor clears the CARB marine engine regulations, it earns the right to bear one of the CARB environmental labels shown in Fig. 10. The BF225/200 will bear the three-star (ULTRA-LOW) label shown at the bottom of Fig. 10.



Fig. 10 CARB environmental label

4.3.3 Knock control system

To obtain the rated output horsepower of 165 kW at 5,500 rpm from the propeller shaft, it was necessary for the engine itself to produce 200 kW, requiring specific output horsepower to be increased to 57 kW/l. Therefore, in addition to the use of the VTEC system and the tuning of the intake and exhaust systems, a knock control system was adopted to maximize the potential output horsepower. The knock sensor is a resonance vibration type, and controls the optimum ignition timing within the 80–90 RON octane number. The adoption of this system has increased power output by 5–6 kW with the throttle fully opened.

4.3.4 Alert control system

(1) Overheat Alert

Because outboard motor cooling systems are operated by direct intake of seawater, etc., into the engine, foreign matter floating on the surface of the water can block the inlet and cooling water channels creating potential for engine overheat and serious engine damage. Overheat sensors, which accurately detect blockages in the water channels, are installed in both banks of the V6 engine providing a system which gives early warning of overheating. The control algorithms are based on those used for the BF130/115. The alert signal is transmitted to the rider by means of a buzzer and a lamp, and then fuel supply and ignition is cut down.

(2) Oil Pressure Alert

The oil pressure alert control algorithm is based on the algorithm used for the BF130/115. Oil pressure is monitored by low and high oil pressure switches, and the alert is set to function in response to engine speed and oil temperature, which has improved the engine protection function. The alert signal is transmitted to the rider in the same way as for the overheat alert described above.

(3) Other Alert Systems

The outboard motor has been provided with warning buzzers and lamps to warn the rider in advance of abnormalities in alternator function and infiltration of water in the fuel tank or fuel lines.

4.4 Weight Saving Technology

4.4.1 Resin inlet manifold

Considerations of strength and rigidity lead to a change in material for the inlet manifold from aluminum to nylon. Fig. 11 shows an external view of the inlet manifold.

As Fig. 12 shows, the inlet manifold is composed of three injection-molded components formed from nylon 6 and joined by vibration welding. Accurate control of the welding surface to form a single unit was achieved by setting all the joint surfaces on a single plane, enabling consistent welding quality.

The inlet manifold utilized in the BF225/200 was made flat to enable reduction of the front and rear length of the engine cover, which created the necessary opening for installation of the variable intake valve cover. To improve pressure resistance with this configuration, strength is ensured by simultaneously vibration welding six supports around the opening for installation of the cover.

Support and rib configurations were optimized by analyzing pressure resistance and vibration using CAE, which included analysis of the welded sections. This enabled designers to ensure sufficient strength, with a Nominal thickness of under 4 mm. Application of these technologies has resulted in significant weight savings, with the new manifold approximately half the weight of the previous aluminum inlet manifold.



Fig. 11 External view of inlet manifold



Fig. 12 Structure of inlet manifold

4.4.2 Resin ECU case

ECU's normally generate a great deal of heat due to built-in ignition igniters. And the ECU case is typically made of aluminum to dissipate radiant heat, but this increases weight significantly. The igniter has subsequently been built in to the ignition coil, and the heating circuits have been positioned on the base plate to improve radiation of heat. This has controlled the ambient temperature around the ECU when installed in the engine, making it possible to use nylon resin for the ECU case. The height of the electronic components has also been reduced, and the former bath tub shape of the case has been changed to an envelope shape, enabling the use of less plastic material in the injection molding process and resulting in a weight reduction of more than 30% over the previous model. The new low profile of the ECU has also improved mounting flexibility. The ECU is shown in Fig. 13.



Fig. 13 ECU

4.4.3 Optimization of bracket system components

To achieve weight savings in the stern bracket system, CAE analysis models (Fig. 14) of the stern bracket which fixes the outboard to the boat and the swivel case which supports the steering shaft were used to examine the relationship between static and dynamic breaking loads in actual brackets. The high load-bearing sections were identified, enabling the form to be optimized to balance strength with weight savings.

As a result, the weight of the bracket system has been reduced 20% compared to the previous model (BF130/115).

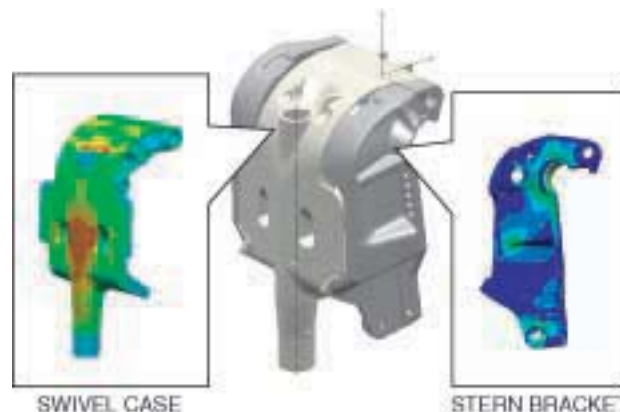


Fig. 14 CAE model of strength

4.5 Engine Cover With Center Handle

Four stroke outboards require that the user check the engine oil level periodically. A burden is placed on the user when removing the engine cover, as they are large, heavy, and difficult to carry. A lightweight, easy to carry engine cover was therefore developed for the new outboard. The engine cover of the previous model was designed with a combined tilt-up handle and an air intake at the rear. Because the new engine is larger, a special carrying handle was designed in the center of the upper surface of the cover. The rim molding previously utilized in the BF130/115 was adopted, resulting in an engine cover 7.1 kg lighter than a 2stDI engine cover. Fig. 15 shows an external view of the engine cover and an image of how it is carried.



Fig. 15 Center handle engine cover

4.6 New Anti-corrosion Painting

As previously mentioned, the low exhaust gas emissions and high fuel economy of the BF225/200 make it friendlier to the environment. In addition, to make the production process environmentally friendlier, a non-chrome paint was adopted for the external components of the new outboard.

To ensure corrosion resistance when outboards are used in saltwater, aluminum alloy external components are treated with an anodic oxidation coating, to which paint is then applied.

The anodic oxidation coating leaves porous layer that can act as starting points for corrosion. Previously, a molybdenum disulfide and nickel acetate treatment was applied to seal this porous layer, and reinforce the anodic oxidation coating. However, when deep scratches occur to the paint surface, the molybdenum disulfide crystallizes, allowing the advance of corrosion without the formation of a passive state film to protect the aluminum surface.

To prevent this, a primer containing chrome, which has been proven effective against corrosion, is typically applied between the aluminum and the topcoat to form a passive state film. Chrome has been entirely eliminated in the new anti-corrosion paint utilized for the BF225/200 by impregnation of the porous layer with phosphate zirconium and sealing with nickel acetate to reinforce the anodic oxidation coating. Because phosphate zirconium does not crystallize, it forms a passive state film between the aluminum surface and the paint which prevents corrosion even when deep scratches occur to the paint surface. The addition of a primer containing molybdenum phosphate has further strengthened the film. This has done away with the necessity of utilizing chrome in the painting process, while at the same time

achieving a level of corrosion resistance equivalent or superior to that of the current method. Fig. 16 shows a cross-sectional image of the paint layers formerly used and those used on the new outboard motor.

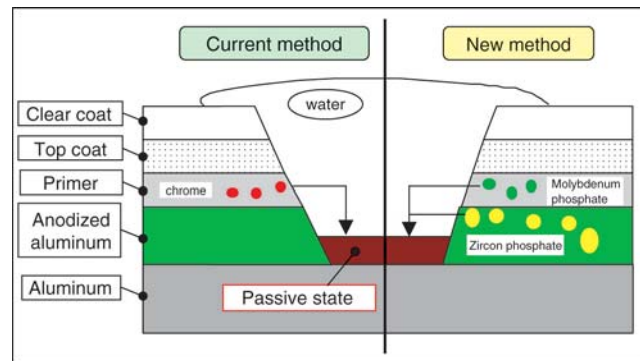


Fig. 16 Cross-sectional image of outboard paint

5. Results of Development

5.1 Performance

The adoption of power-enhancing technologies such as VTEC a variable intake system and a knock control system, combined with weight-saving technologies such as plastic inlet manifold and analysis of the bracket system, have enabled acceleration performance of the BF225/200 equivalent to that demonstrated by competitors' 2stDI outboard motors, as shown in Fig. 17.

5.2 Low Vibration

The adoption of a 60° V6 engine, natural torque axis support mounts (center axis of rotational motion established by reactive force of combustion), and rubber mounting with non-linear spring characteristics have reduced the level of vibration of the new outboard to less than half that of competitors' 2stDI outboard motors. Fig. 18 shows craft vibration levels, which are shown as non-linear rubber mount spring characteristics in Fig. 19.

5.3 Low Noise

To maintain compactness, a large capacity intake silencer has been installed to the upper section of the engine. As Fig. 20 shows, this has reduced engine noise more than 3 dBA against competitors' 2stDI outboard motors.

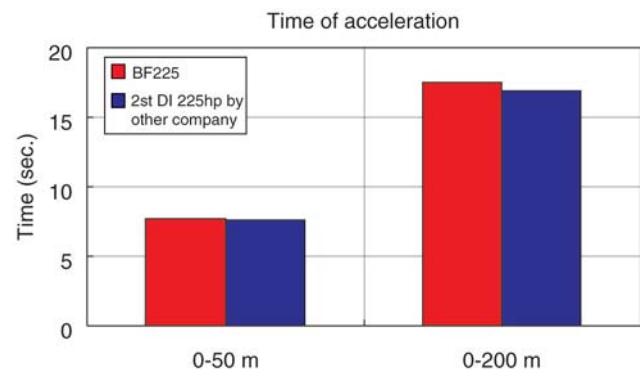


Fig. 17 Comparison of acceleration time

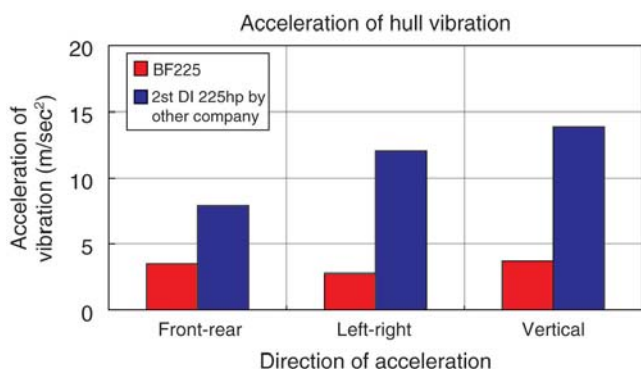


Fig. 18 Comparison of vibration level

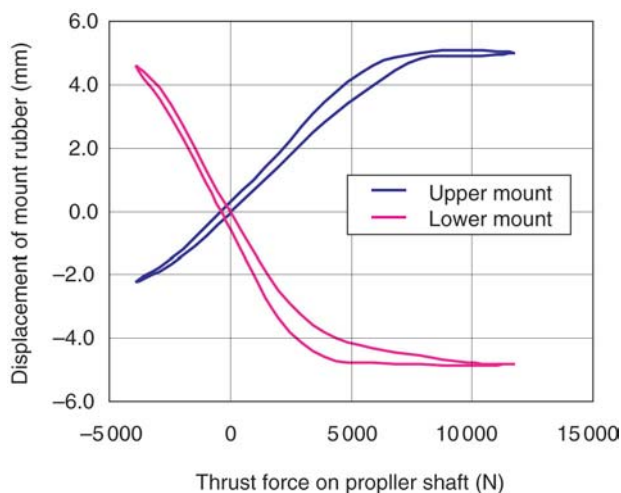


Fig. 19 Displacement of mount rubber

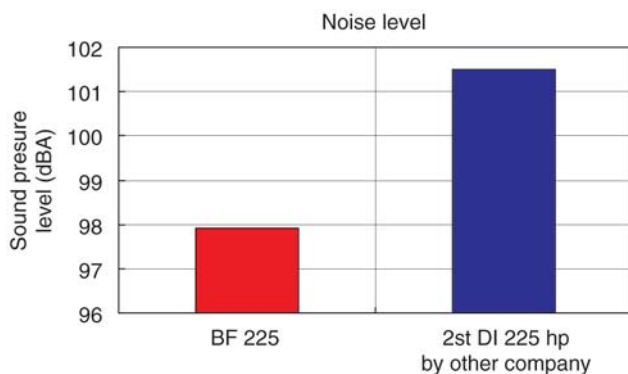


Fig. 20 Comparison of noise level

5.4 Ease of Installation

Frequently, users of outboards in the power class of the BF225/200 choose to install two motors on a single boat (twin installation). When twin outboards are installed, it is normal to position the motors as close as possible to the center of the boat, to prevent the propellers from leaving the water when turning. Four-stroke outboard motors conventionally have a larger size than two-stroke outboards of equivalent power. In addition, the valve system of V6 engines tends to increase their total width. The BF225/200 features a "V-wing Form", in which the width of the front of the engine cover is reduced. This allows twin outboards to be installed in a 660 mm span, the smallest mounting span in the market, and a world first for 200 HP class four-stroke outboard motors.

This means that users making the transition from competitors' two-stroke outboard motors do not need to increase the installation space on their boats.

Fig. 21 compares twin installation of the BF225/200 and another company's two-stroke outboard. Fig. 22 shows a bird's-eye view of twin BF225/200s at full steering.

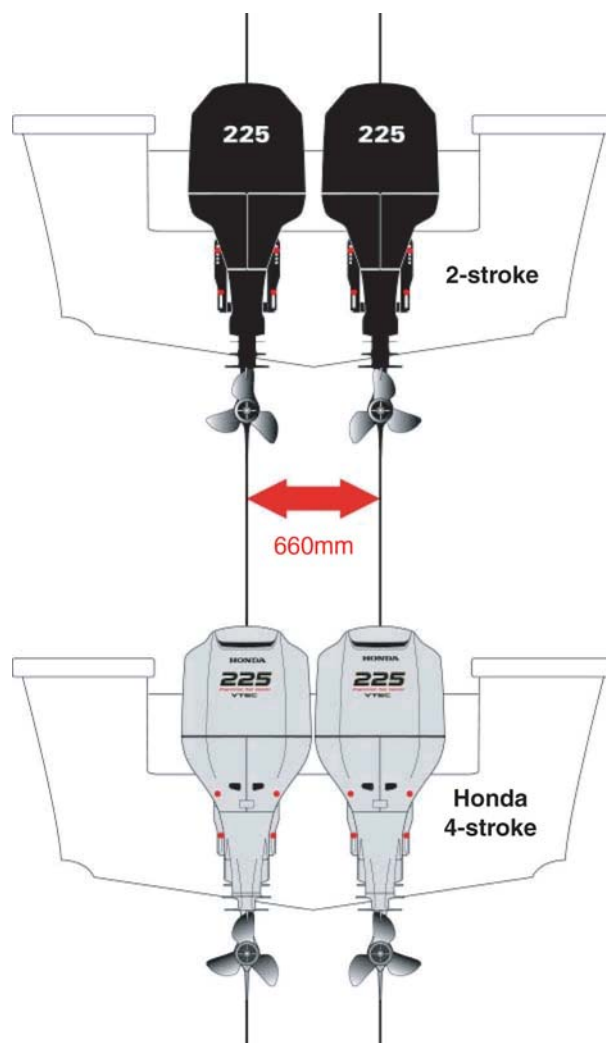


Fig. 21 Installation of twin outboard motors

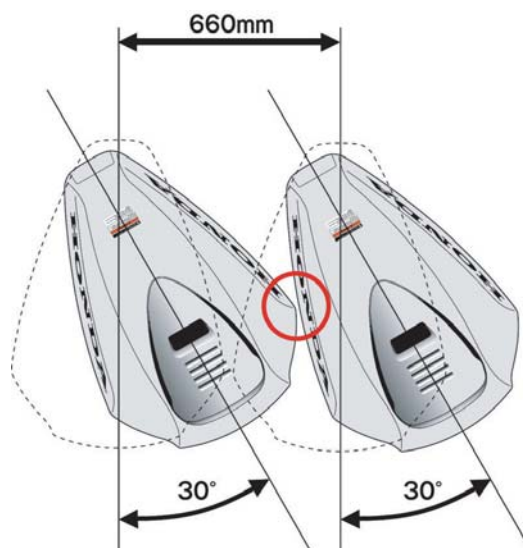


Fig. 22 Twin installation at full steering

6. Conclusion

The BF225/200 has been provided with VTEC, a variable intake system, a plastic inlet manifold, a knock control system, and a water-cooled exhaust manifold to ensure equivalent power and ease of mounting to existing 2stDI outboard motors in the same class. At the same time, PGM-FI and an O₂ feedback system enable high power and fuel economy with a low level of exhaust gas emissions. Parts sharing with an automotive engine and the sharing of an automotive production line for cylinder blocks and cylinder heads has further achieved high reliability and reduced costs.

These technologies have enabled Honda to present the BF225/200 (Fig. 23) to the market as its flagship model, with the world's highest power for a four-stroke outboard motor, and to expand its four-stroke outboard line-up from 2 HP to 225 HP models.

In closing, the authors wish to express their sincere thanks to the many people, at factories both in Japan and overseas, representing both Honda and other companies, who generously offered their assistance in the development of this new outboard.



Fig. 23 Boat with twin BF225s at cruising speed.

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