

Development of Gear Case for Large Outboard Motor

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ABSTRACT

As part of the development process for its flagship large outboard motor, the BF250, Honda has developed a gear case for large outboard motors in order to realize increased reliability and power performance against existing models.

Enhanced tooth contact has been achieved through redesign of the structure of the bearing mountings, and pitting resistance has been increased by modifying the gear materials and heat treatment. In addition, gear specifications making it possible to realize high durability under high loads have been employed, and the optimization of tooth contact via finite element model (FEM) analysis with consideration of stiffness and manufacturing variations has assisted in the realization of a tooth grinding process that reduces manufacturing variations.

These innovations have resulted in the realization of a gear case that achieves class-topping power performance while satisfying targets for durability performance.

1. Introduction

Today, there is a tendency towards the use of increased horsepower capacity in offshore boats manufactured mainly in Europe and North America. A high proportion of these outboard motors are employed under conditions of prolonged use at high loads in boats for professional use, and durability and reliability are therefore demanded.

This paper will discuss the technologies applied in a gear case for a large outboard motor as part of the development of the BF250⁽²⁾ in response to these demands. Figure 1 shows the external appearance of the gear case.



Fig. 1 External view of gear case

2. Demands on Drive Systems of Large Outboard Motors and Development Goals

Professional (commercial and government) use of boats fitted with large outboard motors represents approximately 30% of the market, with standard leisure use making up the remainder. This proportion of professional use is high in comparison to other horsepower ranges (Fig. 2).

A great deal of professional use is conducted under severe conditions of high loads for extended periods, making a high level of durability an important factor.

While use time in the high-load range (3850 rpm to

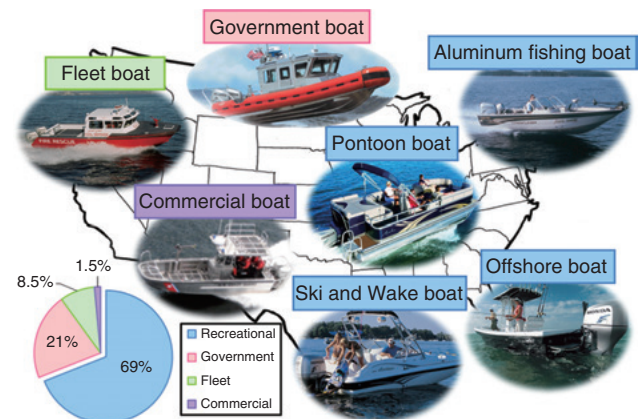


Fig. 2 Variety and percentage of large boats in the market

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WOT) is thought to represent 30% or less of total use time for conventional professional use, in the case of boat taxis (tourist boats) the figure is double this at 60% (Fig. 3).

Figure 4 shows boats used for applications such as boat taxis and coastal patrols as examples of this type of extended high-load operation.

Because the submerged gear case represents a resistance when the boat is in operation, it is necessary to increase durability while satisfying power performance demands.

Based on the above considerations, the following aims were set for the development discussed here:

- Realization of class-topping power performance (Balancing maximum speed performance and acceleration performance)
- Realization of adequate durability for high-load operation for extended periods (Realization of level of durability twice or more as high as a conventional gear case in component durability tests)

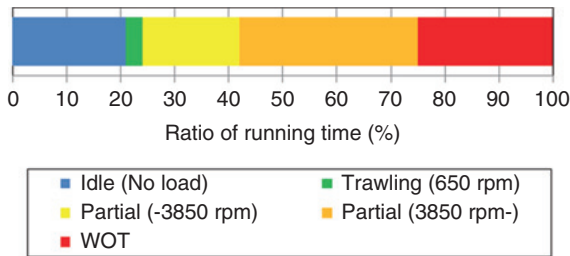


Fig. 3 Ratio of running time represented by different loads for boat taxi



Fig. 4 Boat taxi and coastal patrol boat

3. Basic Structure of Outboard Motor Gear Case

The basic structure of an outboard motor gear case orthogonally transforms power from the engine shaft by

means of pinion and bevel gears, and transmits the power to the propeller shaft. The structure considers the support of propeller thrust, the minimization of water resistance, and the realization of watertightness. Figure 5 shows this basic structure.

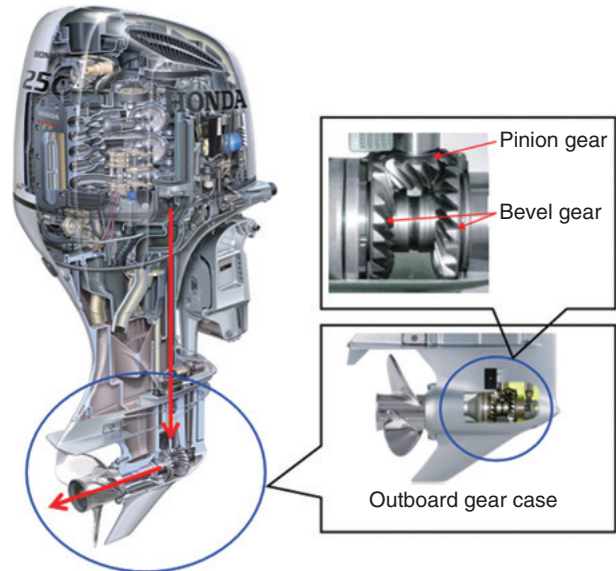


Fig. 5 Standard outboard gear case

4. Main Technologies

This section introduces the element technologies employed in the developed gear case.

4.1. Gear Case Specifications

The setting of a reduction ratio at the commencement of the design process is an important factor in the design of a gear case. Outboard motors differ from four-wheeled and two-wheeled vehicles in that the ultimate transmitter of power is a propeller, and the diameter of the propeller produces differences in propulsion efficiency. For this development project, the propeller diameter and reduction ratio producing the highest efficiency in the representative speed range for professional use were selected. Figure 6 shows the relationship between these parameters, with a comparison with a conventional gear case.

In order to increase durability while modifying the reduction ratio of the gear case, the diameter of the bevel gears was increased by 10% against a conventional gear case. This increased underwater resistance by 2.4% against a conventional gear case, but optimization of the case's shape based on a computational fluid dynamics (CFD) analysis of the pressure on the surface of the unit made it possible to reduce its C_d by 5%.

Figure 7 shows the results of CFD analysis of the pressure on the surface of the gear case.

4.2. Configuration of Bearings

4.2.1. Basic structure of bearings

Prior to discussing the basic structure of the bearings, this section will provide a brief discussion of methods used when fitting large outboard motors. Normally, the propeller of an outboard motor rotates clockwise when seen from behind. This is known as the standard rotation specification. In some cases, however, a boat might be fitted with two outboard motors, as shown in Fig. 8. When this is the case, if the direction of rotation of the propellers were the same, the torque reaction force would be high, affecting the boat's straight-line stability. Because of this, when two motors are fitted, opposite directions of rotation are employed for the propellers of the right and left motors, mutually canceling out torque reaction force and helping to maintain straight-line stability. The specification of the motor in which the propeller is rotating counter-clockwise when viewed from behind is termed the counter-rotation specification⁽¹⁾.

Turning to the current basic structure of the bearings, because the direction of propeller rotation differs for the standard and counter-rotation specifications even when the direction of engine rotation is the same, it is necessary to use a different position for the forward gear for each specification. Because of this, the structure of the bearings differs for each specification. At present, tapered bearings,

which are able to bear thrust load, are employed for the frequently used forward gear, while ball bearings are employed for the less frequently used reverse gear.

Figure 9 shows the difference between these structures.

4.2.2. Modification of structure of bearings for counter-rotation specification

A consideration of the direction of the tapered bearings in Fig. 9 shows that they face in the same direction for both the standard and counter-rotation specifications.

In the case of the standard rotation specification, both the gear thrust force and the propeller force act in the same direction; both loads are able to be received by the outer ring of the tapered bearings, and gear tooth contact is stable regardless of propeller force. By contrast, in the counter-rotation specification, because the gear thrust force and the propeller force act in opposite directions, unless the propeller force is greater than the gear thrust force, the loads cannot be received by the outer ring of the tapered bearings, and gear tooth contact becomes unstable. In the newly developed gear case, rather than supporting the forces separated by

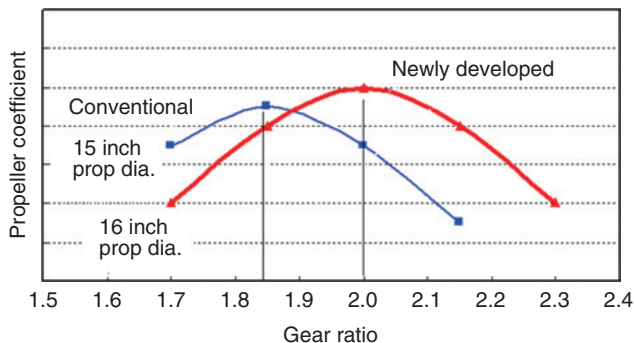


Fig. 6 Gear ratio and propeller coefficient

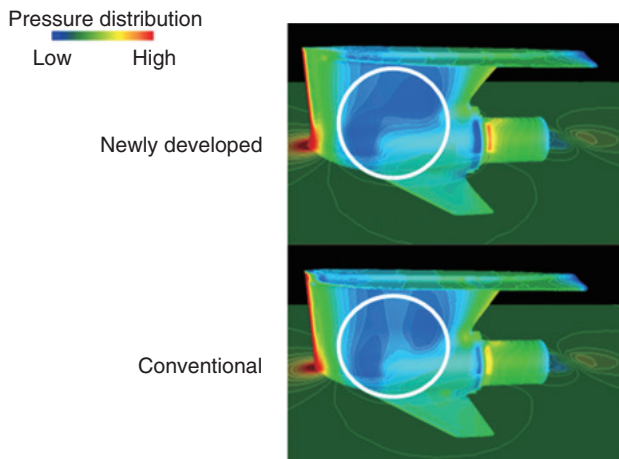


Fig. 7 Pressure distribution

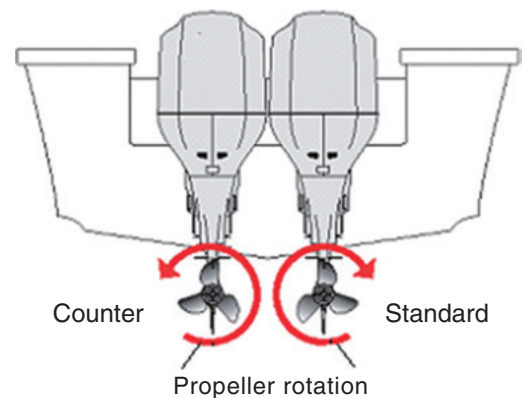


Fig. 8 Twin outboard motors

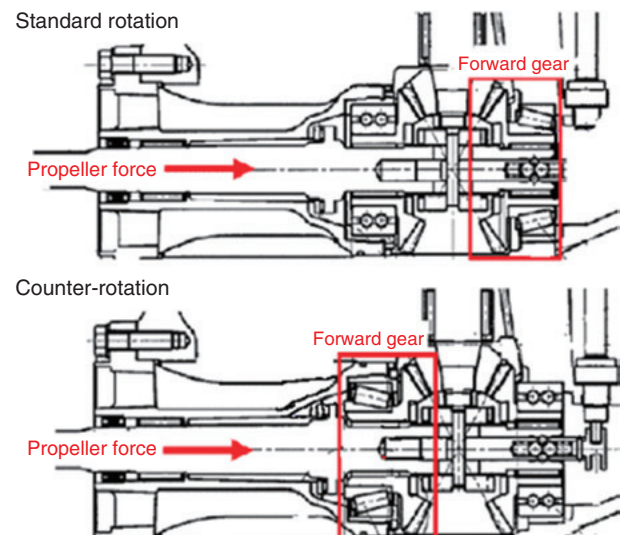


Fig. 9 Structure of gear case

the gears by a single set of bearings, different bearings are employed to receive each load. In this configuration, the radial force is received by needle bearings, and thrust force is received by thrust bearings. This has helped to realize constant stability in gear tooth contact, and has increased durability. This configuration is shown in Fig. 10.

4.3. Gear Materials and Heat Treatment

A setting was established for the hardness of the gears in order to help ensure pitting resistance. Because the tooth shape is adjusted by grinding in the developed gear case, the degree of grinding was taken into consideration, and it was judged that a hardness distribution that maintained a high level of hardness to a depth of around 0.3 mm from the surfaces of the teeth in comparison to the conventional specifications would be necessary to help ensure resistance to both pitting originating at the surfaces and pitting originating internally. New heat treatment conditions were set in order to realize this goal, and the use of a high-alloy steel (containing, among other components, 2% Ni and 0.75% Mo) made it possible to achieve the necessary toughness for the gears while realizing the target hardness distribution (Fig. 11).

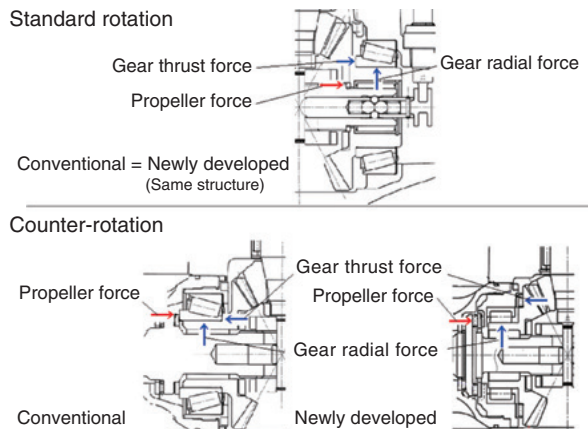


Fig. 10 Detail of gear case

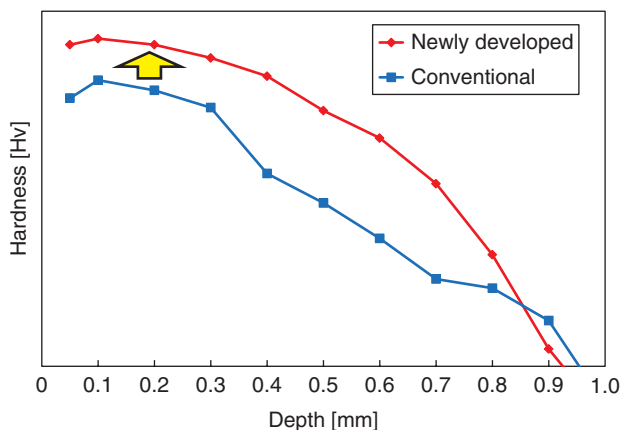


Fig. 11 Hardness distribution

Figure 12 shows the results of roller pitting fatigue tests conducted to verify the effectiveness of these measures. The production of the test specimens modeled actual gear manufacturing methods as much as possible, including grinding of the teeth in order to remove their surfaces.

The developed specifications achieved an increase in pitting strength of approximately 10% against the conventional specifications.

4.4. Gear Specifications and Tooth Shape

One of the characteristics demanded from the gears employed in a large outboard motor is sufficient durability for operation under high loads for extended periods. The development discussed here therefore optimized the gear module, using FEM analyses in order to achieve a balance between tooth face pressure, tooth root stress, and stiffness. Figure 13 shows the difference in the shapes of the conventional and the developed gears.

Because the gears in large outboard motors are used under high loads, the gear case undergoes considerable distortion, and the level of displacement of tooth contact from the clearance of the bearings is high. Measurements of gear displacement and FEM analyses were therefore conducted in order to correct the shape of the teeth and realize appropriate tooth contact. In addition, grinding is employed to reduce variations in tooth shape during production to the greatest possible extent, thus realizing reproducibility of tooth contact. Figure 14 shows an example of the FEM analyses that were conducted.

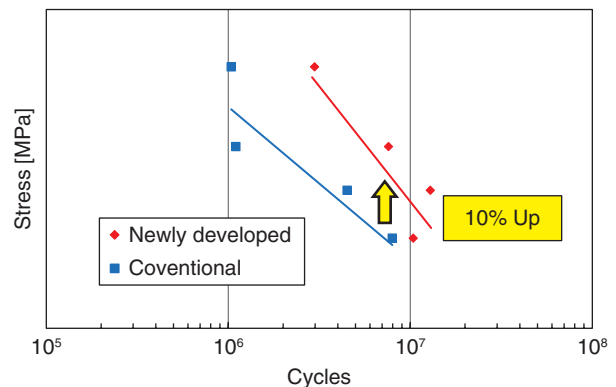


Fig. 12 Results of fatigue test for pitting

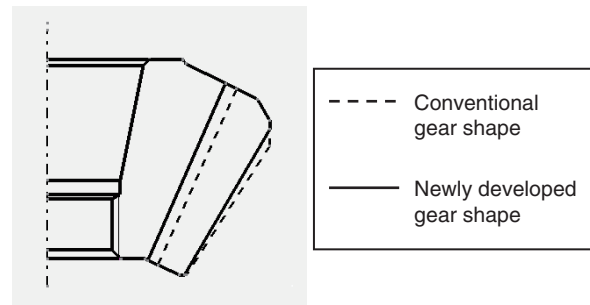


Fig. 13 Comparison of pinion gear shape

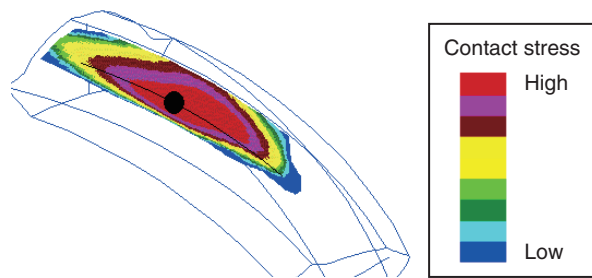


Fig. 14 Example of FEM

5. Durability Performance and Power Performance

5.1. Durability Performance

In component durability tests, the newly developed gear case displayed three times the durability time of a gear case using a conventional design, exceeding the target of twice the durability time (Fig. 15).

5.2. Power Performance

Optimization of the gear ratio and reduction of the water resistance of the gear case, while realizing increased durability, made it possible to achieve class-topping power performance, balancing maximum speed performance and acceleration performance (Fig. 16).

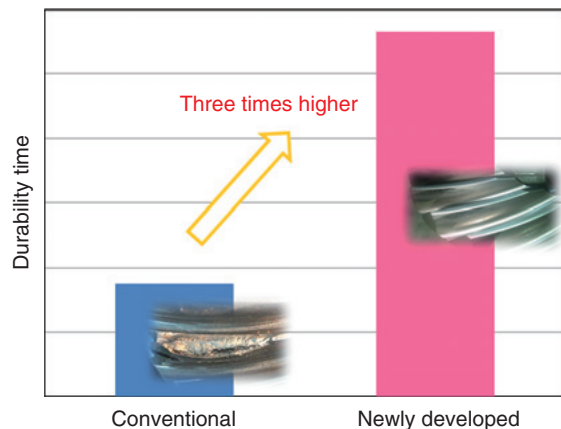


Fig.15 Durability

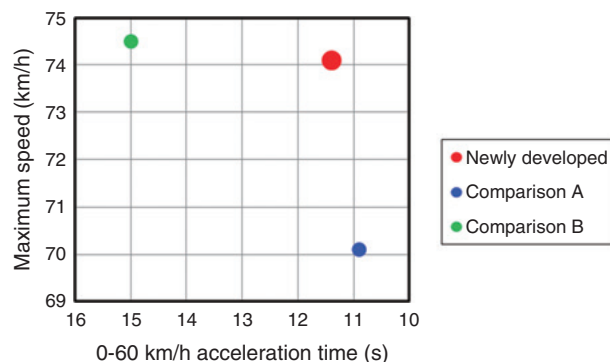


Fig. 16 Maximum speed and 0-60 km/h acceleration time

6. Conclusion

The development of a gear case for a large outboard motor resulted in the achievement of

- Class-topping power performance
- Three times greater durability as demonstrated in component durability tests

These results were achieved as follows:

- (1) Optimal specifications were selected based on the relationship between reduction ratio and propulsion efficiency, and water resistance was reduced.
- (2) The bearing structure for the counter-rotation specification was redesigned, helping to ensure stable tooth contact irrespective of operating conditions.
- (3) Gear materials and the heat treatment applied were reconsidered, making it possible to realize a high level of hardness on the outermost surfaces and the surface layers of the gear teeth, increasing pitting resistance by approximately 10%.
- (4) The gear module was optimized with consideration of durability under high-load operation. In addition, FEM analyses considering stiffness and manufacturing variations were conducted in order to optimize tooth contact, and grinding has been applied to finish the gear teeth.

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