Proceedings of the International Gas Turbine Congress 2003 Tokyo
November 2-7, 2003

Turbocharger Technology for Personal Water Craft

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ABSTRACT

IHI launched the first production turbocharger for Personal Water Craft (PWC) in 2002.

A 4-cycle petrol engine was desired by the PWC market to meet emissions regulations. However, 2-cycle engines still had the advantage of max horsepower with small package design. The environment required that a 4-cycle engine boosted by turbocharger make much more power. We have been trying to overcome some of the challenges to realize a high-performance turbocharged engine for PWC application.

INTRODUCTION

A 2-cycle engine is usually applied for PWC due to greater power at the same hull size compared to a 4-cycle engine. However, recent emissions regulations for marine vehicles, for example CARB (California Air Resources Board) and the EPA (Environmental Protection Agency) limits approach the same levels as those established for automotive use.

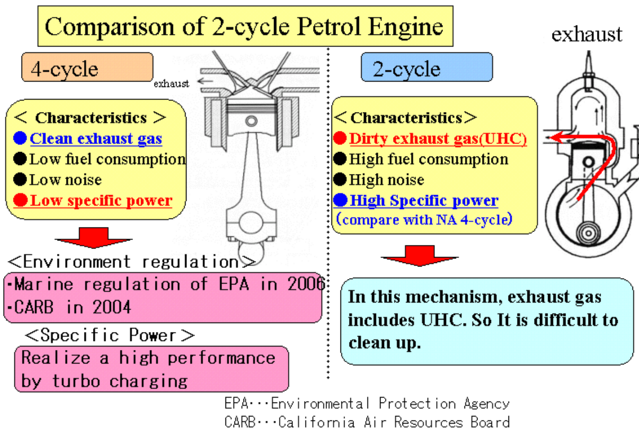

FIG.1 Characteristics of 4-cycle engine

We had to achieve the following targets to satisfy the performance and reliability criteria for PWC use.

1) Maximum output higher than 2-cycle engine.
2) Quick engine response similar to naturally aspirated
3) Durability of water-cooled turbine housing under 1173K gas temperature conditions.
4) Corrosion resistance of turbine housing cooling passage and turbocharger exterior under sea water conditions.

Manuscript Received on May 28, 2003

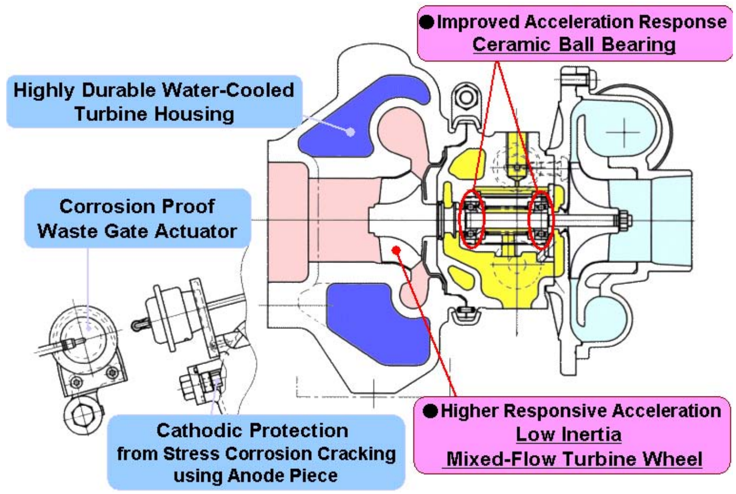

FIG.2 IHI RHF5WB Turbocharger

DESIGN FEATURES

Table.1 Turbocharger specifications

Model	RHF5WB type
Compressor	$\phi 52.5$
Turbine	$\phi 44.5$
Max Turbine Speed	180000rpm
Turbine Inlet Gas Temperature	1173K

DEVELOPMENT

a. To Deliver both High Power and Quick Response –

The mixed flow turbine wheel can make high flow and high performance at the rated power point without losing quick response due to its low inertia design (Minegishi, 1995). The weight of a mixed flow turbine impeller with shaft is 20% less than a radial turbine, and the inertial moment is reduced by 55% . Fig. 4 shows the acceleration response based on the simulation of a 2L petrol engine with an initial speed of 20 km/hr. This result shows that the acceleration time with a mixed flow turbine is improved by 20% over a radial turbine.

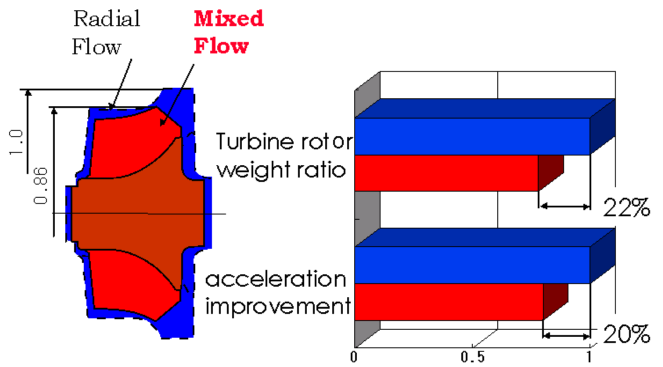

FIG.3 Mixed Flow Turbine

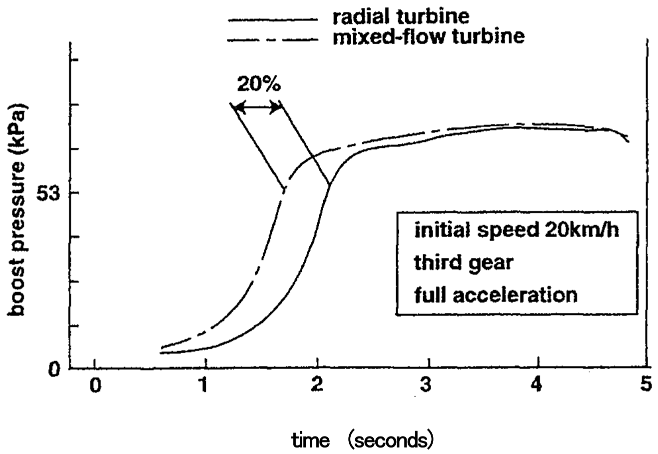

FIG.4 Response simulation of 2L petrol engine (effect of mixed flow turbine)

Ball bearings contribute to quick engine response due to less mechanical loss compared to the typical plain bearing structure (Fig.2). In the bearing section two angular type ball bearings are arranged to face each other. Bearing inner races are inlaid on the turbine shaft to receive radial force and thrust forces in both directions. The outer races are inserted into the oil film damper placed in the bearing housing (Miyashita, 1987).

Fig. 5 shows that mechanical loss with ball bearings is reduced by about 60% compared with plain bearings. Lastly, we applied ceramic balls to reduce inertia moment and to achieve high durability. The simulation result (Fig.6) carried out with the same condition shows that the response time with ball bearings is 9% shorter than with plain bearings.

We optimized the operating point for PWC. Fig.7 shows the difference of the matching point for max power and PWC use. Usually turbochargers for marine petrol engines are matched for max power intention. But PWC performance demands both quick response time and max power, similar to a motorcycle. We optimized the compressor design to reduce the surge-line and peak efficiency.

Using the combination of a mixed flow turbine and ball bearings, we achieved both quick response time, an improvement of one tenth for the first term, and high max power, the highest power in PWC.

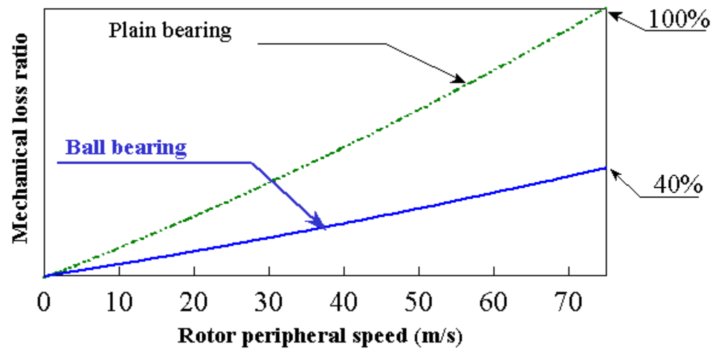

FIG.5 Mechanical loss of bearing

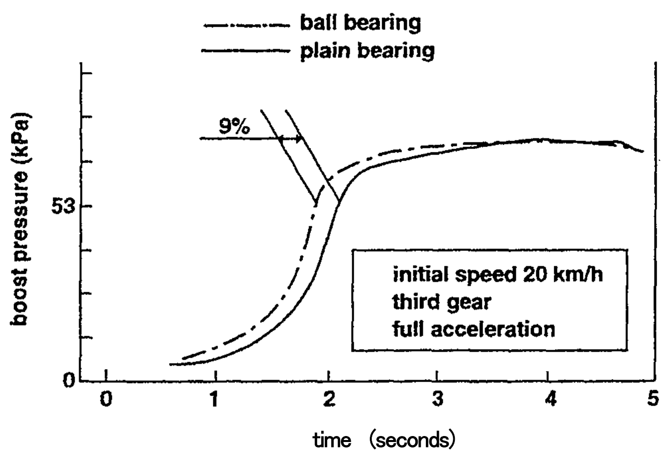

FIG.6 Response simulation of 2L petrol engine (effect of ball bearings)

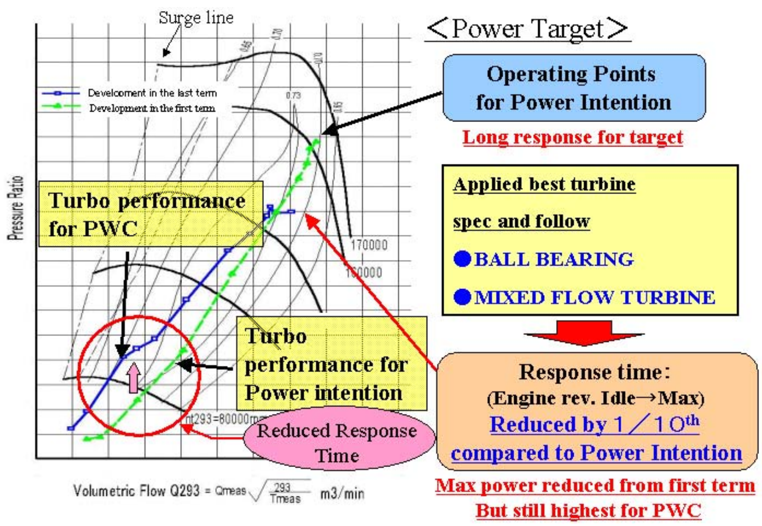

FIG.7 Compressor operation points for PWC relative to power intention

b. Development of Water-Cooled Turbine Housing Under the 1173K Exhaust Gas Temperature –

To prevent explosion and for user safety, water-cooled turbine housings are commonly applied in marine engines. However, the maximum gas temperature typical of diesel use is 973K to 1023K, and a waste-gate actuator is not needed for that performance. In the case of PWC, it may reach 1173K, which can cause tremendous heat stress on the wall between the gas passage and the water passage. Also, to achieve a wide range of operating points, we must apply a waste-gate, which makes water passage design complicated (Fig.8). Thus, we must consider heat stress along with casting productivity.

Fig.9 shows FEM stress analysis of the turbine housing. In this analysis, the stress at the tongue point of the exhaust gas passage is very high. Basically, increasing wall thickness at the tongue point reduces stress. However, performance is very sensitive to the shape of this point. Therefore the water passage design is optimized to minimize the stress on this point while maintaining high performance

Additionally, the design was optimized to prevent casting defects by considering the casting process. We realized both durability and quality with a complex design that has a waste gate port and water jacket.

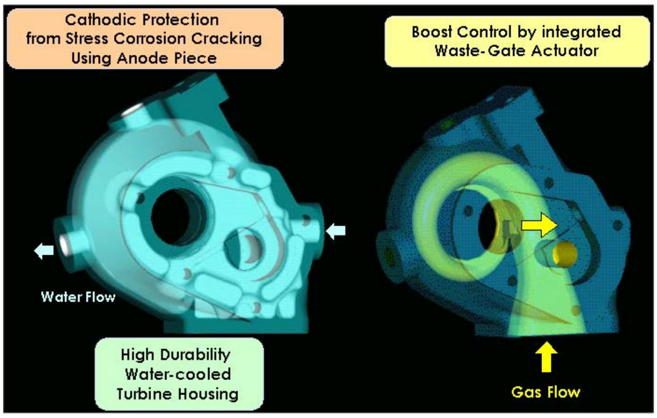

Fig.8 Schematic of gas flow and water flow passage in turbine housing

c. Countermeasure to Corrosion of Turbine Housing Water Jacket against Sea Water –

Several instances of stress corrosion cracking (SCC) have been experienced in seawater pumps and brine circulation pumps made of the Type 2 austenitic cast iron (Miyasaka and Ogure, 1987). This turbine housing material is the same austenitic cast iron, but with an effective protection method against SCC applied.

A zinc anode piece for corrosion proofing is put on top of a bolt installed outside of the turbine housing and goes through into the water passage. Based on our test result Fig.10, the electric potential values at several points inside of turbine housing were out of the critical range of possible corrosion by using this structure.

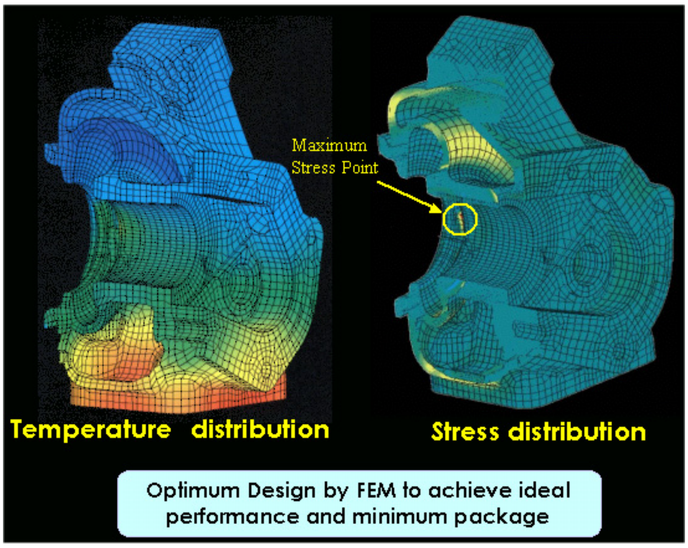

Fig.9 FEM stress analysis of turbine housing

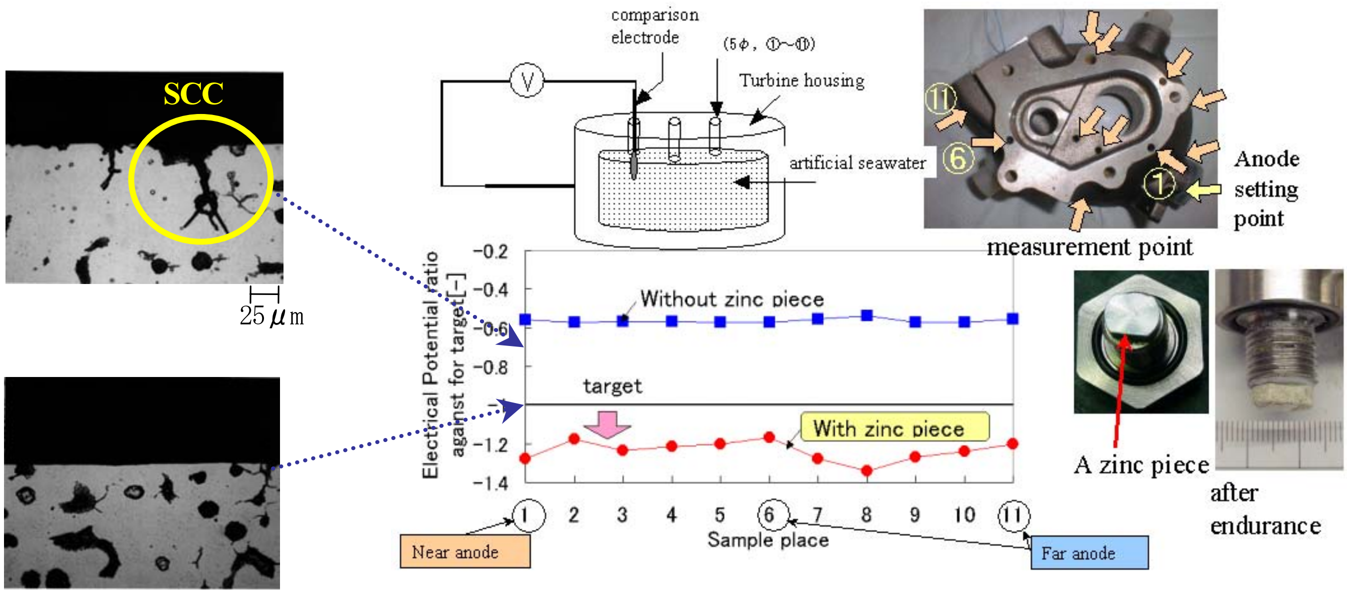

Fig.10 Cathodic protection for turbine housing

CONCLUSION

We were able to meet the requirements for PWC applications with a combination of new technologies. As a top manufacturer in this area, IHI will proceed with development to meet higher targets of performance and durability.

ACKNOWLEDGMENT

The authors would like to thank HONDA R&D CO., LTD for giving their supports and opportunity.

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