DEVELOPMENT AND APPLICATION OF LARGE MARINE HYBRID TURBOCHARGER FOR GENERATING ELECTRIC POWER WITH EXHAUST GAS FROM THE MAIN ENGINE

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Abstract: *There has been an increasing demand for energy efficiency and low emission. To maximize exhaust gas energy recovery, MHI-MME has developed a hybrid turbocharger system (HB TC System) for marine diesel engines. HB TC System has a high-speed generator/motor directly coupled to turbocharger's shaft resulting in very high energy efficiency. This paper introduces design features and estimated performance of MHI-MME's first hybrid turbocharger MET83MAG.*

Keywords: *Hybrid turbocharger, Energy efficient, Maximise exhaust gas energy recovery, Waste Heat Recovery system.*

Classification number: *2.1*

1. Introduction

A turbocharger consists of a single-stage turbine and a compressor on a shaft. The compressor is driven by engine exhaust gas directed to the turbine, and it supplies pressurized air for combustion to the engine. With recent increases in the efficiency of diesel engine turbochargers, sufficient air can be fed to the engine with partial exhaust-gas capture for electricity generation. A practical use of this technology is for a waste heat-recovery system, feeding approximately 10% of the exhaust gas to a power turbine to drive the generator. An electric power-recovery system with a generator directly connected to a turbocharger was developed in 2009 by Mitsui Engineering & Ship Building Co., Ltd., using a large turbocharger.[1] Our hybrid turbocharger comprises a generator in the turbocharger body, but it only needs a space as wide as a conventional turbocharger and requires only small changes to a conventional diesel engine.

The turbocharger can be used as a generator and also as a motor through the application of bidirectional frequency converters. We reduced the size of the generator and designed it to fit inside the turbocharger structure to realize these functions. The turbocharger was installed on board a ship, and operations were started after successful completion of a turbocharger engine-matching test and sea trials. This report describes the electric power generation effect on the engine performance.

2. Advantages of Our Hybrid Turbocharger

A hybrid turbocharger integrated with generator uses exhaust-gas energy at the turbocharger inlet port to generate electricity, just as a conventional gas power turbine does. However, compared with a conventional power turbine, our hybrid turbocharger has the following advantages:

- The system is free from thermal and piping losses, and the turbocharger turbine provides high efficiency.

- The turbocharger can be accelerated by utilizing the generator as a motor.

The power output of the resulting three-phase alternating current (AC) electricity cannot be directly utilized on a ship, as the frequency depends on the turbocharger rotation speed. The AC from the generator is rectified to a direct current (DC) and converted to the ship electricity voltage and frequency through an inverter. The type of our converter is an active rectifier based on an insulated-gate bipolar transistor (IGBT). These power converters are bi-directional. The electric power supply from the ship allows the use of a generator as a motor to accelerate the turbocharger. A two-cycle low-speed diesel engine is usually assisted by an electric blower to enhance the combustion airflow rate from the turbocharger during low-load operations. The motoring function of our turbocharger can be used as an assisting blower, and the high-efficiency compressor in the turbocharger can be used to reduce the required electric power.

3. Construction of Our Hybrid Turbocharger

Figure 1 shows a cross-sectional view of the first MET83MAG hybrid turbocharger. The generator was downsized so that it could be installed in the silencer.

The main problem encountered during the design was the cooling structure of the generator. The passage of cooling water and air, and lubricating oil from outside were integrated in the housing during the downsizing. The time-proven sliding bearing of the MET53MA turbocharger was adopted for the generator bearing without modification.

The generator seal structure with the sealing air and labyrinth seal prevented lubricating oil from leaking into the input shaft and stator. The electricity generated from the hybrid turbocharger supplied the entire electrical demand of the ship during normal cruising.

Therefore, the DC/AC inverter was required to maintain the correct output power frequency and voltage as well as to ensure the power factor of the ship power source and to maintain capacity to supply the required short-circuit current. Figure 2 shows views of the frequency converters (AC/DC converter and DC/AC inverter).

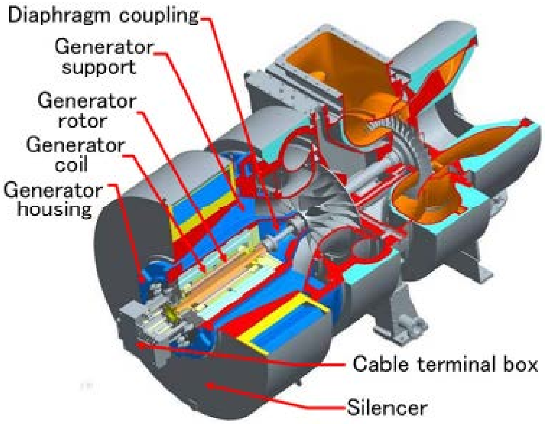


Figure 1. *Cross-sectional view of the MET83MAG hybrid turbocharger.*

Figure 2. *External views of frequency converters.*

4. First Hybrid Turbocharger Test Results

4.1. Bench tests

The development of the first MET83MAG hybrid turbocharger (without a motoring function) was started at the beginning of 2008.

Bench tests were conducted at MHI-MME in May 2010 to verify the turbocharger's performance.[2] In these bench tests, the generator characteristics were verified through various generator performance tests, including its load characteristics, governor characteristics, and temperature rise, as well as the turbocharger performance.

The sudden load change (increase/decrease) and temperature rise test results are shown in Figure 3, 4, and 5 respectively.

In Figure 3 and 4, the transient frequency fluctuation at sudden load change was ±10% or less, as specified by the Rules and Regulations for the Classification of Ships, and the frequency recovered to ±1% or less of the rated frequency within 5 seconds. In the temperature-rise test, the temperature at each part was verified to be within the designed values at an environmental (atmospheric) temperature of 35 deg.C.

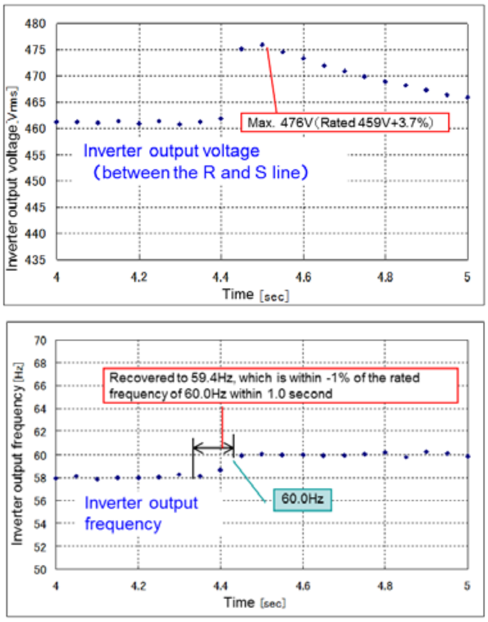


Figure 3. *Results of the sudden load change (decrease from 550 kw to 0 kw) bench test.*

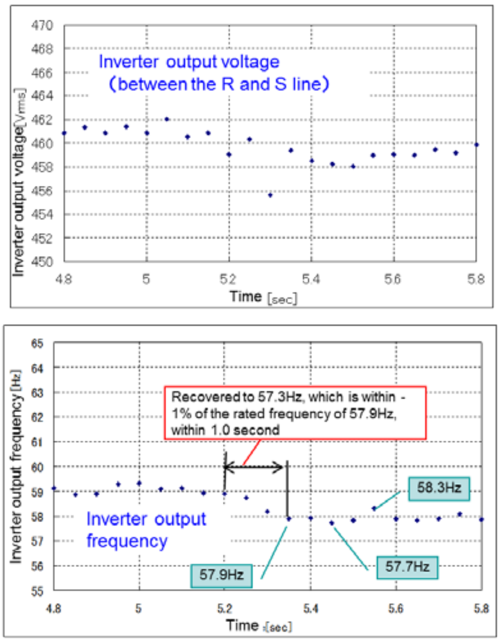


Figure 4. *Results of the sudden load change (increase from 250 kW to) bench test.*

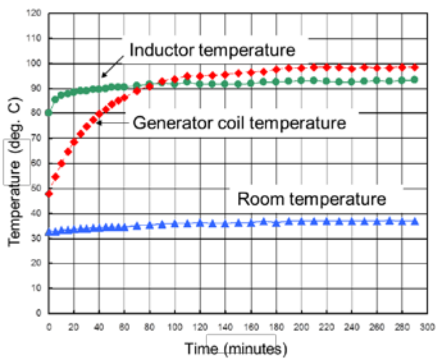


Figure 5. *Results of the temperature-rise bench test(560kW generating power).*

4.2. Engine-matching Test

After the bench tests at MHI, the MET83MAG hybrid turbocharger was installed in a low-speed 7S65ME-C diesel engine developed by the engine builder, and an engine-matching test was conducted in December 2010. A photograph of the turbocharger installed on the main engine is shown in Figure 6, and the results of the turbocharger performance tests are shown in Figure 7. Verification tests were conducted to determine whether power generation started at 60% or more of the main engine rated load and whether independent operation was available to supply all of the ship's electrical demand at 75% or more of the engine load. The predetermined generation power was attained while satisfying the required turbocharger efficiency at a main engine load of 75% or more, as shown in Figure 7. The effect of the turbocharger on the engine operating points with and without power generation was checked on the compressor map, and a sufficient surge margin was confirmed. Also, sudden load change tests were conducted to confirm the effect of transient generator-load changes on the turbocharger operation. The results are shown in Figure 8. The turbocharger rotational speed became stable approximately 30 seconds after the sudden load change, and surging was not observed.

Figure 6. *Engine-matching test using a Hitachi Zosen Corporation 7S65ME-C engine*

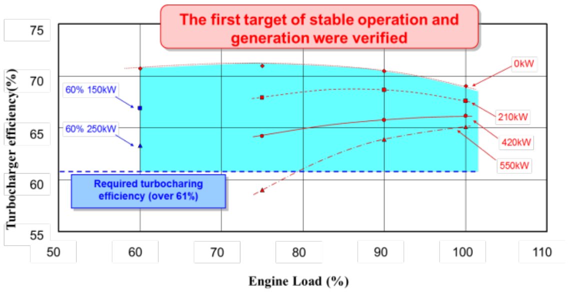


Figure 7. *Results of the engine-matching test.*

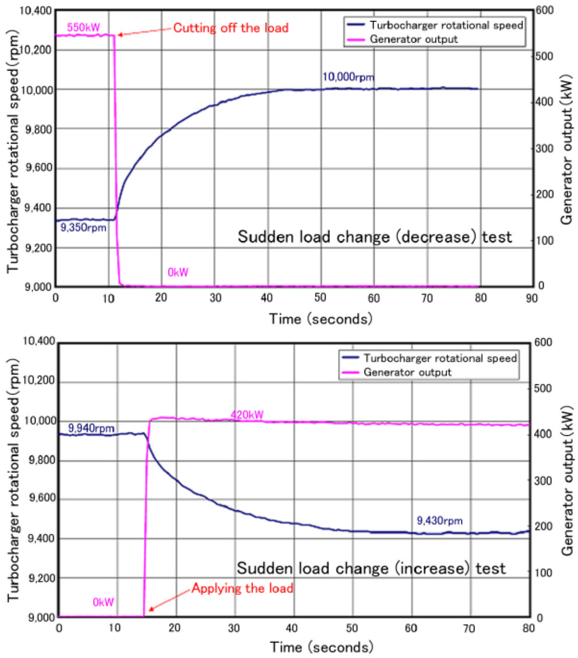


Figure 8. *Sudden load change (decrease/increase) test results with the turbocharger installed on engine.*

4.3. Results of sea trials

Sea trials of the ship in which the MET83MAG was installed were conducted at the Japan Marine United Corporation in April 2011. During the sea trials, parallel operation of the hybrid turbocharger and diesel generator and stand-alone operation of the hybrid turbocharger–generator were tested. A stable and continuous power supply was verified when all of the ship’s power demand was supplied by the hybrid turbocharger, even after a sudden change in the ship’s power demand.

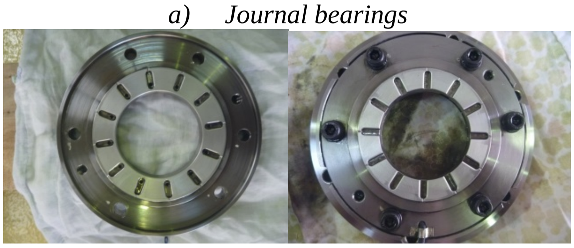
Currently the bulk carrier with the MET83MAG hybrid turbocharger (Figure 9; ship name: SHIN KOHO) is in service, and NYK Line is verifying practical operation of the turbocharger in collaboration with Fukujin Kisen.

Figure 9. *Picture of a ship with the installed hybrid turbocharger.*

5. Overhaul inspection of generator after 5 years.

MHI-MME confirmed the bearing condition of generator after 5 years. Main engine running hour is 26,591 hours. The bearing condition at overhaul inspection shows Figure 10. The bearing conditions are good and continuous use.

a) Journal bearings



b) Thrust bearings

Figure 10. *Picture of bearings for generator.*

6. Motoring function test result.

The generator employed in this hybrid turbocharger arrangement can also be operated as a motor and is capable of applying driving force to the turbocharger rotor. That is, by using the electric motor to assist that turbocharger rotor during low-load operation, it can take the place of the auxiliary blower used during the running of two-cycle engines at low load. [3]

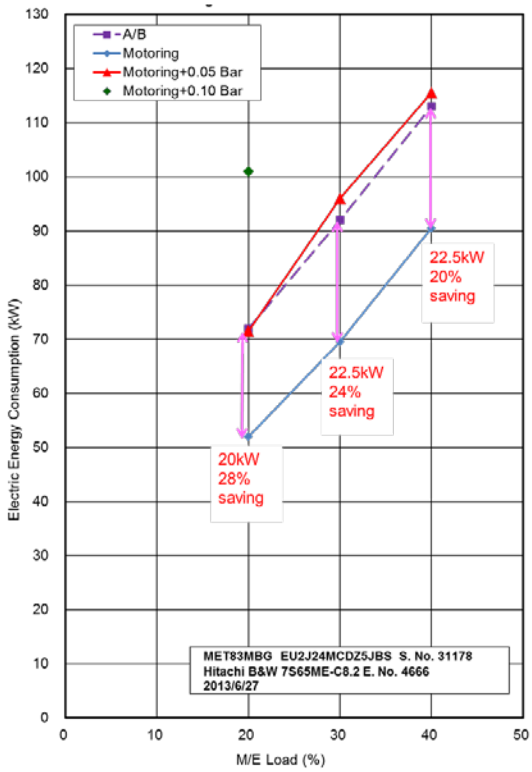


***Figure 11**. Motoring test on engine.*

MHI-MME confirmed the motoring function on engine. Figure 11 compares test results for a conventional auxiliary blower and electric power assisted operation. At engine load of 20%, 72kW of electrical power is needed for the blower, while the same scavenging air pressure is delivered by electric power assisted operation requiring only about 52kW. This represents a savings of 20kW.

7. Conclusion

MHI-MME has developed the hybrid turbocharger MET83MAG in collaboration with NYK Line, MTI, and Japan Marine United Corporation. This is the world's first practical application of a marine hybrid turbocharger. The turbocharger not only recovers electric power from excessive energy in the engine exhaust gas but also controls the air sent to the engine for combustion by controlling the power-generation rate. These characteristics are quite different from those of conventional turbochargers, whose operation depends solely on the engine output. These characteristics allow us to apply various energy-saving measures to meet environmental regulations. We would like to expand the available turbocharger sizes to match additional practical operation conditions.

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