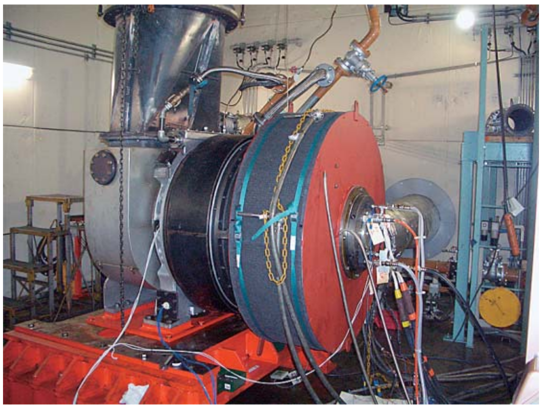

Hybrid Turbocharger with Integrated High Speed Motor-generator

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1. Introduction

Owing to the sharp rise in the cost of fuel oils and a strong demand for cutting CO_2 emissions in recent years, attention is riveted on how to wrestle with reducing the fuel consumption of the diesel engine. The entire exhaust gas discharged out of a diesel engine is normally forwarded to turbochargers. On the other hand, a new power generating system has already been put into practical use, in which for the sake of energy recovery a part of the exhaust gas is fed to a turbine to drive an electric generator instead of being fed to the turbocharger. This system is called the turbo-compound system, where approximately 5 % of the engine power is diverted to a turbine generator and recovered as electric power. Since the turbocharger is now operated by a smaller amount of gas, the amount of the air to be fed to the engine is decreased. As a result, the temperature of the exhaust gas will rise, allowing the recovery of the heat by an exhaust gas boiler driving a steam turbine, while the revolution energy of the turbocharger turbine is used for compression of the combustion air. **Fig. 1** shows the system diagram of a Turbo-compound System in which electric power is generated by these two additional turbines.

The revolution energy of the turbocharger rotor on the diesel engine is used for compression of the combustion air. The Hybrid Turbocharger, consisting of a turbocharger rotor connected to a motor-generator for directly converting part of the above-mentioned revolution energy into electric power, possesses the following features:

(a) Neither additional power turbine and its accessory equipment nor any piping thereto is necessary, requiring almost no excess space.

(b) Utilizing its function as an electric motor, the performance of the turbocharger system can be improved especially at part load (with the two cycle engine it can substitute for the auxiliary blower).

(c) Owing to that there is no pressure loss in the exhaust gas line and that energy conversion is carried out in the turbine of the turbocharger, high turbine efficiency can be achieved.

The outline description of the Hybrid Turbocharger developed by Mitsubishi Heavy Industries, Ltd. (MHI) is given hereunder:

2. Efficiency of turbocharger and recovery of exhaust heat

The efficiency of a turbocharger is defined as the ratio of adiabatic heat drop at the outlet/ inlet of the compressor of the turbocharger against that at the

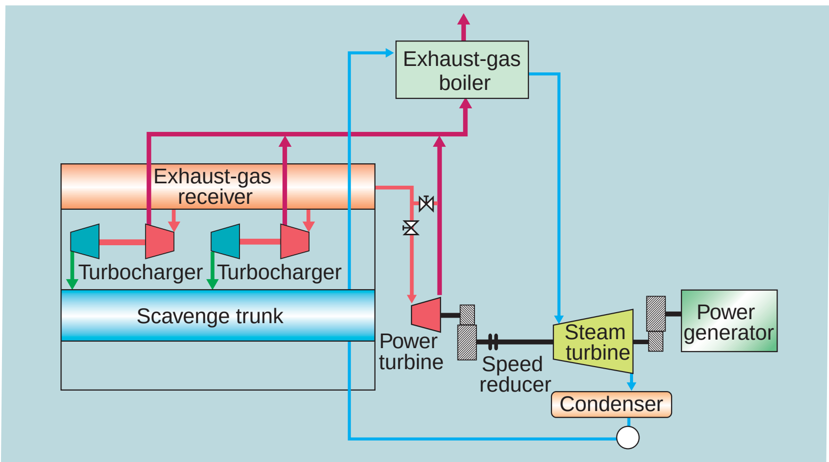

Fig. 1 Systematic diagram of turbo-compound system

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outlet/inlet of the turbocharger turbine. Therefore, the higher the efficiency of the turbocharger becomes, the less the energy is required for compressing the air. In general, with the rise of the efficiency of the turbocharger, the flow rate of the air fed to the engine is increased, bringing an improved fuel consumption rate, and as a result the temperature of the exhaust gas will fall. On the other hand, this may cause a shortage of steam from the exhaust gas boiler, which is installed on the downstream side of the turbine exit of the turbocharger, requiring occasional adjustment of the turbocharger efficiency.

With a turbo-compound system, part of the exhaust energy will not be transferred to the turbocharger and thus not utilized in compressing the air. Since such non-utilization might appear equivalent to the deterioration in turbocharging efficiency, although we can obtain the required temperature of the exhaust gas, it is desirable to use a turbocharger that can achieve high performance efficiency so that a large amount of energy may be recovered while maintaining a specified level of engine performance.

The Hybrid Turbocharger under manufacture of MHI was developed on the basis of the latest MET-MA series. As a result of reviewing particularly the turbine design, improvement in the efficiency of the turbocharger by 2 points has been realized in comparison with the former MET-SE‡U series. **Fig. 2** shows a comparison of the efficiency of the turbocharger between the MET-MA and MET-SEII series.

3. Constitution of Hybrid Turbocharger

(1) Power generator

The prototype of the hybrid turbocharger was developed on the basis of Model-MET42MA. This turbocharger is designed to be used on 5000 kW-class diesel engines. The output of the generator is selected at 250 kW on the premise that 5 % of the engine output is recoverable. **Table1** shows the major specifications of the motor-generator, which is a 4-pole permanent magnet synchronous type. **Fig. 3** shows the cross-sectional diagram of the motor-generator.

(2) Power electronics

Since the generated output power by the motor-generator is a high frequency three-phase alternating current, it is necessary to rectify it into direct current, and thereafter reconvert into 60 Hz alternating current. In order for the equipment to function as both a generator and an electric motor, an active rectifier using a high-speed switching device are employed instead of a simple diode bridge. Although the MET42MA turbocharger is comparatively small-sized, the frequency of the output generated by a 4-pole synchronous generator running at about 20,000 RPM is remarkably high, requiring very good engineering to cope with it. However, developing a power electronics system practically applicable to the high RPM mentioned above, and evolving the developed system to large-sized turbochargers can be carried out rather easily, in our view.

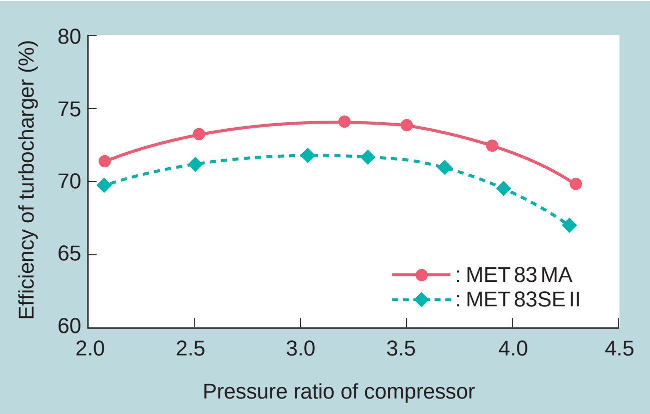

Fig. 2 Efficiency comparison of turbocharger between MET83SE II and MET83MA

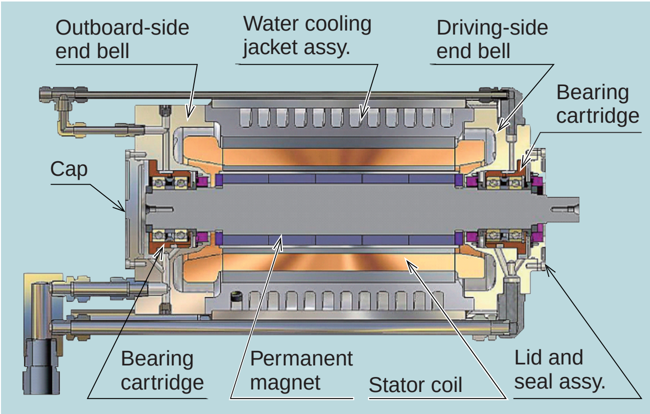

Fig. 3 Cross-sectional diagram of motor-generator

Table 1 Major specifications of the motor-generator

Rated RPM (min^{-1})	18 700
Maximum permissible RPM (min^{-1})	22 400
Separate-exciting power generator	Permanent magnet synchronous type
Poles	4
Output voltage	3-phase AC 400-480 V
Maximum output:	252 kW@18 700 min^{-1}
Bearings	Ceramic ball bearings
Lubrication	External forced lubrication
Cooling	Air, water
Net weight (kg)	130

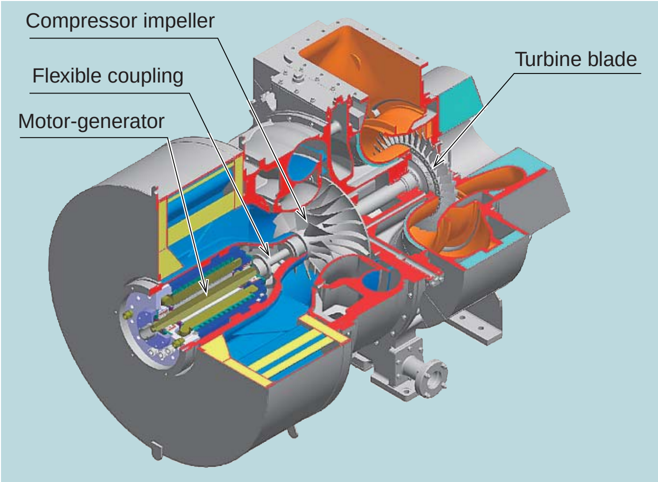

Fig. 4 Cross-sectional diagram of Hybrid Turbocharger

Fig. 5 Hybrid Turbocharger under assembling

(3) Main body of the turbocharger

Fig. 4 shows the cross-sectional diagram of a hybrid turbocharger. From the compressor scroll chamber toward the turbine side, there is no structural difference with a standard turbocharger. To accommodate the motor-generator inside the air intake silencer, a shell component to support the motor-generator is constructed in the space between the silencer and compressor. Furthermore, the outer diameter of the silencer is enlarged to secure ample space for the air duct while containing the motor-generator in the center part of the silencer. The motor-generator is connected to the rotor shaft via a flexible coupling.

4. Running test of hybrid turbocharger

Fig. 5 shows a hybrid turbocharger under construction. The operation was executed using the operation facilities for normal type turbochargers. While taking respective measurements of vibration of the rotor shafts and the temperature of bearings for the turbocharger and the generator, the subject equipment was confirmed to be operable without any problems up to the maximum permissible revolution of 22,300 min^{-1} irrespective of the amount of generated power. In addition, it has been confirmed that by supplying electric power to the motor-generator of the hybrid turbocharger to make it function as an electric motor, the rotor of the turbocharger can be accelerated. Henceforth, we are planning to next verify the relationship between the amount of the electric power supplied and the improvement of the supercharging capacity.

5. Conclusion

The hybrid turbocharger can be installed with almost no reconstruction to the existing diesel engine. Besides, we can recover not only electric power from the excess energy but also optimize the engine performance by changing the RPM at will through controlling the amount of the generated power. Furthermore, by using the generator-motor as an electric motor we can improve the turbocharger's performance, particularly liable to be short at the low-load range of the engine. MHI have completed a hybrid turbocharger by integrating a motor-generator into the MET42MA-type turbocharger, and finished mechanical operation tests. We have scheduled tests on the quality of the electric power generated by the hybrid turbocharger, then upon obtaining a favorable result, to connect it to a commercial electric power system. In addition, the hybrid turbocharger can substitute for the auxiliary blower used in a low-speed 2-cycle diesel engine. With application to low-speed marine engines kept in mind, we are henceforth intending to put the hybrid turbocharger to practical use while proceeding to enlarge its applicable size and to optimize adaptability to the 2-cycle engine.

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