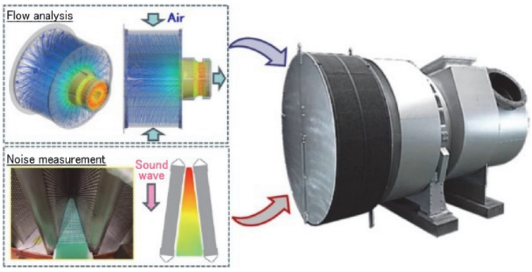
Development of a New Silencer Supporting Large-Capacity MET Turbocharger: Achieving Both High Performance and Low Noise



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In recent years, the development of marine turbochargers for two-stroke engines has shifted toward higher volume flow turbocharger designs. Consequently, noise levels from these turbochargers have also tended to increase, making it necessary to achieve reduced noise while satisfying performance requirements. One method for reducing noise is the use of silencers, which are also installed in MET turbochargers. As design requirements become increasingly stringent, Mitsubishi Heavy Industries, Ltd. has made efforts to develop silencers and associated design tool by utilizing analysis and measurement technologies, aiming to acquire capabilities to achieve a silencer design that is balanced at a high level. Through various tests, including operation as a turbocharger, the performance of the new silencer has been evaluated. In addition, it is expected that silencer designs capable of meeting various needs, such as higher performance and lower noise, can be realized. This report describes the results of these efforts.

1. Introduction

One of the key devices addressing the noise reduction requirement in Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) products is a silencer. Silencers have been applied to a wide range of products. MET turbochargers are among such products equipped with a silencer. Ambient air is drawn through the silencer mounted on the intake side into the turbocharger unit. To meet the needs for higher performance and lower noise, while also satisfying various other needs such as cost reduction and higher quality, the realization of advanced silencer design technology is essential, and also extremely important for enhancing product value and strengthening competitiveness. MHI has undertaken initiatives to develop technology targeting silencers for MET turbocharger to meet the diverse product needs described above, aiming to acquire capabilities to control silencer characteristics. This report describes MHI's development status of the MET silencer, technological development of which has been advanced through specification studies, operational testing, and other processes.

2. Marine turbocharger (MET turbocharger)

Marine two-stroke engines are widely adopted as main engines for large vessels such as container ships undertaking long-distance voyages due to their high combustion efficiency and power characteristics. For this type of engine, efficient scavenging is essential because the exhaust and intake processes occur simultaneously. Exhaust gas turbine turbochargers are high-speed rotating devices that utilize the energy from engine exhaust gases to drive a turbine, which in turn drives a compressor mounted on the same shaft that draws in ambient air through a silencer and pressurizes the intake air. This enables the supply of more air into the cylinders, achieving improved combustion efficiency and increased power output.

Mitsubishi Heavy Industries Marine Machinery & Equipment Co, Ltd. introduced the completely non-cooled MET turbocharger to the market in 1965. Since then, continuous development has been conducted to meet various demands from engine manufacturers, such as higher output and greater efficiency, and in 2025, MET celebrated its 60th anniversary.

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MET turbochargers have become one of the global standards for marine engines.

Axial-flow turbine types are primarily used for two-stroke engines, whereas radial turbine types are used for small four-stroke engines. As the latest model of the axial-flow turbine type, the MET-MBII series has been released (1). This turbocharger is designed with a concept of achieving a 16% increase in capacity compared to the previous MET-MB model. When achieving the same engine output, the MET-MBII turbocharger with one or two frame sizes smaller compared to the MET-MB turbocharger can be applied, leading characteristically to reductions in initial cost, weight, and maintenance costs.

Marine turbochargers are required to have high durability, reliability, and maintainability. To withstand long-term operation at sea, they must be designed to operate stably under high-temperature and high-pressure environments, and the selection of materials resistant to corrosion and wear is also crucial. On the other hand, since marine turbochargers are high-speed rotating devices and their noise can be an issue, it is essential to design an appropriate silencer. The basic performance required for silencers is the ability to effectively attenuate noise in a wide band. In addition, minimization of pressure loss is required in consideration of the effect on performance, and heat resistance and corrosion resistance are also required. In particular, excessive pressure loss reduces turbocharger efficiency and adversely affects engine performance, and therefore, silencers are required to have an internal structure optimized in terms of fluid dynamics.

As described above, turbochargers and silencers are important components installed on marine engines. Their future technological innovation is expected to achieve even higher efficiency and lower environmental impact.

3. Development of new silencer

Silencer for MET turbocharger is mounted on the intake side of a turbocharger. Axial-flow turbine types employ a cylindrical silencer with sound-absorbing elements filled with sound-absorbing material arranged radially inside. Specifications vary according to each lineup, and silencers of various sizes exist. In this study, development was advanced for the size MET33 silencer used on the MET-MBII series.

First, the development concept was established. The initial objectives were to establish a simple new silencer specification that would enable free design for both turbocharger efficiency and noise reduction while achieving low cost, and to ensure that the new silencer could provide equivalent performance in terms of efficiency and noise level to the current silencer. To achieve the above objectives early, a silencer shape partially retaining the current model was adopted. Furthermore, by applying systems engineering principles to organize other required specifications and functions, a silencer specification capable of meeting all needs was formulated.

Furthermore, to achieve both low noise and high performance, it is essential to understand the mechanisms and establish advanced design technology. Generally, noise and performance are in a trade-off relationship. Increasing the sound-absorbing area to reduce noise leads to higher pressure loss, resulting in lower efficiency. Conversely, a flow path structure designed to minimize pressure loss may increase noise levels. Therefore, it is necessary to determine the number and length of sound-absorbing elements while ensuring an appropriate flow path area to maximize both turbocharger efficiency and the noise reduction effect. To this end, the internal behavior and noise reduction mechanisms of the silencer were clarified by leveraging MHI's analysis and measurement techniques, and advanced design technology that enables designs to meet various needs was established as well. The details of these initiatives are described in Chapter 5.

4. Characteristic evaluation through prototype testing

A prototype of the new silencer described in Chapter 3 was manufactured, and the validity of the design concept was verified through various tests.

First, speaker test was conducted on the silencer. The test was performed in a semi-anechoic chamber owned by MHI. The noise reduction effect was evaluated by measuring sound pressure levels inside the silencer and on its outer side. **Figure 1** shows the noise reduction level achieved by the silencer in speaker test. It was confirmed that the proposed specification of the new silencer shows noise reduction performance generally equivalent to the current model, therefore, the target of noise reduction performance was achieved.

Next, actual operating test with the silencer installed on a turbocharger was conducted to evaluate the turbocharger performance and noise level. The test was carried out at MHI's factory facilities in Akunoura-machi, Nagasaki City, Nagasaki Prefecture. Since acoustic reflections from the walls were anticipated during the noise measurement in this environment, the microphone was placed inside a box lined with sound-absorbing material to minimize the impact of reflections.

Figure 2 compares the overall noise levels at representative 1-meter points obtained from the operating tests. In Figure 2, Measurement Point [1] and Measurement Point [2] represent the results measured from the front of the silencer and diagonal direction, respectively. The results were generally equivalent to those of the current model, indicating that the noise level target was achieved. Furthermore, as shown in **Figure 3**, efficiency of the turbocharger equipped with the new silencer was also found to be generally equivalent to that with a current model, confirming the validity of the new silencer concept.

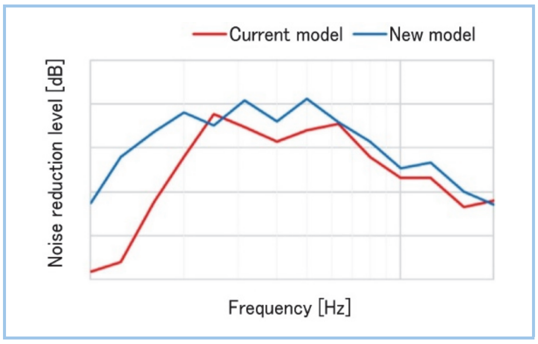

Figure 1 Comparison of silencer noise reduction levels

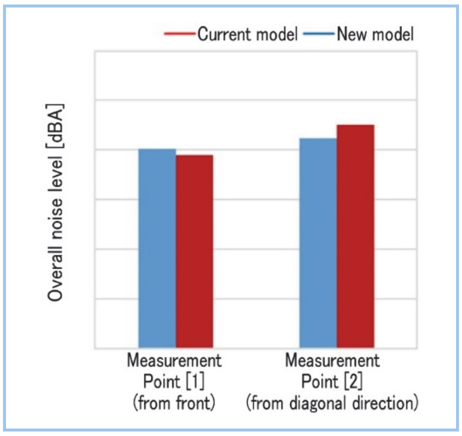

Figure 2 Noise levels at 1-meter points during turbocharger operation

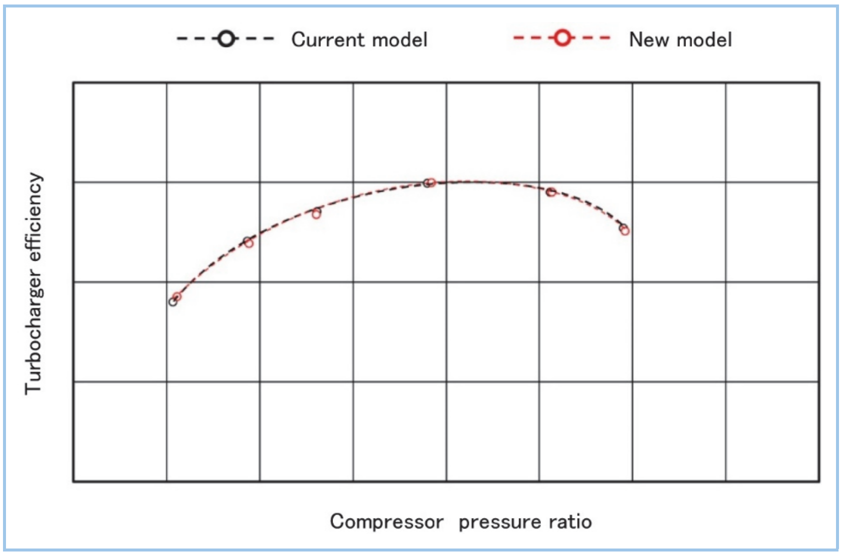

Figure 3 Turbocharger efficiency

5. Establishment of design technology

For the new silencer which concept validity has been confirmed, MHI developed design tools for noise and performance, leveraging its features and considering future market needs.

First, overview of the design tool for noise will be provided. As mentioned earlier, the axial turbine type features a structure where sound-absorbing elements filled with sound-absorbing material are arranged radially. Noise generated by the impeller passes between these elements and radiates outside. The new silencer employs straight-type elements, and in the case of radial arrangement, the flow path width through which sound waves pass becomes wider toward the outer side. To understand the noise reduction mechanism, the internal sound field was visualized using an array of MEMS microphones (2.75 mm x 1.85 mm x 0.95 mm) placed on an electronic substrate (hereinafter referred to as MEMS microphone array). **Figure 4** shows the appearance of the MEMS microphone array. Considering the wavelength of the target sound wave, over 400 MEMS microphones were densely arranged. As shown in **Figure 5**, the MEMS microphone array was mounted in the flow path between the sound-absorbing elements, enabling detailed understanding of the sound pressure distribution. **Figure 6** shows the relative sound pressure distribution at the inlet measured at a representative frequency. **Figure 7** plots the sound pressure variation at a representative frequency along the flow path centerline from the element inner diameter side to the outer diameter side. From these results, it was observed that the sound wave gradually attenuates. In addition, Figure 7 shows that the slope of the relative sound pressure variation becomes slightly gradual near the element outer diameter side, suggesting an impact where the sound attenuation characteristics change as the flow path width (cross-sectional area) increases. By using these results, a noise reduction performance design tool was established that accounts for radial characteristic changes by integrating the noise reduction results calculated for several radially divided sections, based on Doelling's equation [(2)], which is an evaluation formula for noise reduction characteristics under constant cross-sectional area conditions.

Next, this paragraph outlines the performance prediction tool. First, computational fluid dynamics (CFD) analysis was conducted to examine the internal flow structure from the silencer inlet to the impeller inlet in detail. Based on these results, the internal region of the silencer was divided into multiple sections according to flow characteristics as shown in **Figure 8**, and the representative average flow velocity for each section was defined based on the geometric shape of the flow path. Then, a method was established to estimate the internal pressure loss of the silencer through one-dimensional computational modeling. This involves calculating the total pressure loss coefficient individually for each section relative to the dynamic pressure component and integrating them. Furthermore, by converting the calculated effect of the silencer internal pressure loss to the compressor pressure ratio conditions, the effect on the compressor efficiency can be estimated.

Consequently, a path has been established toward achieving a silencer that delivers equivalent performance (efficiency, noise) to current models, which was the objective initially set, while enabling flexible design to meet diverse needs using the established design technology. However, while the results presented in this report are valid for the targeted size MET33, their expansion to the entire product lineup and the validity of the design tools for such expansion remain unvalidated. In the future, MHI will continue to examine these unvalidated matters, aiming to acquire capabilities to flexibly respond to various needs for silencers and turbochargers.

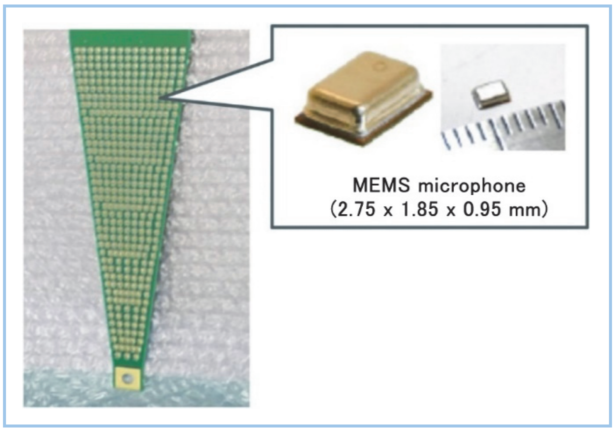

Figure 4 MEMS microphone array

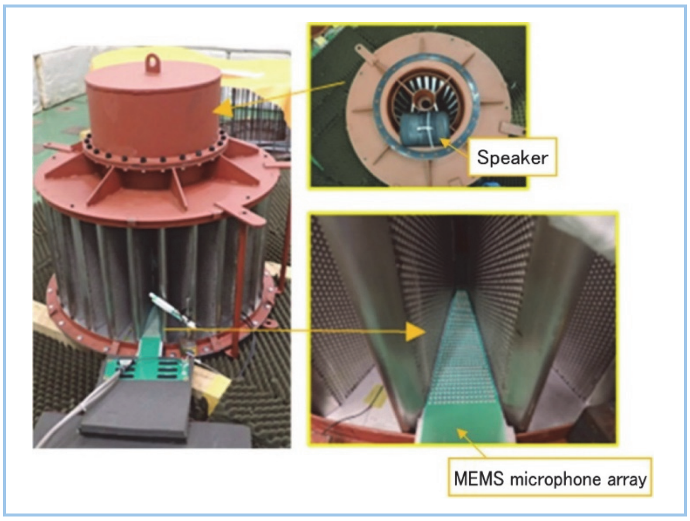

Figure 5 Overview of sound pressure distribution measurement

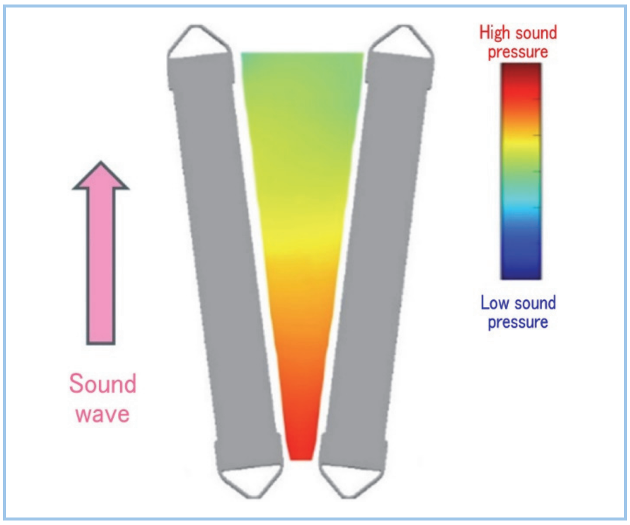

Figure 6 Visualization of sound pressure distribution between sound-absorbing elements

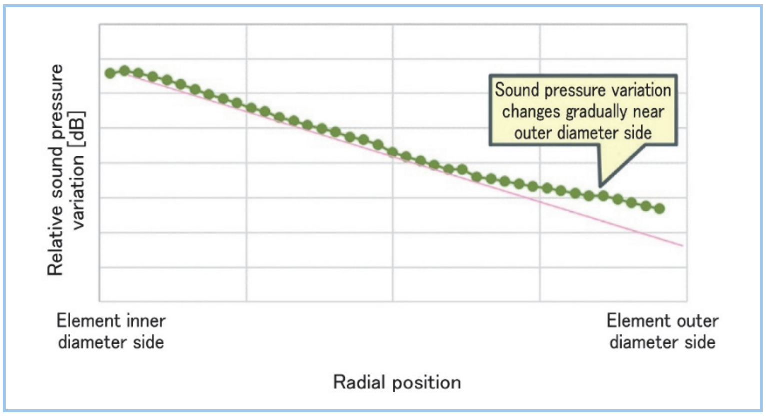

Figure 7 Sound pressure variation at representative frequency

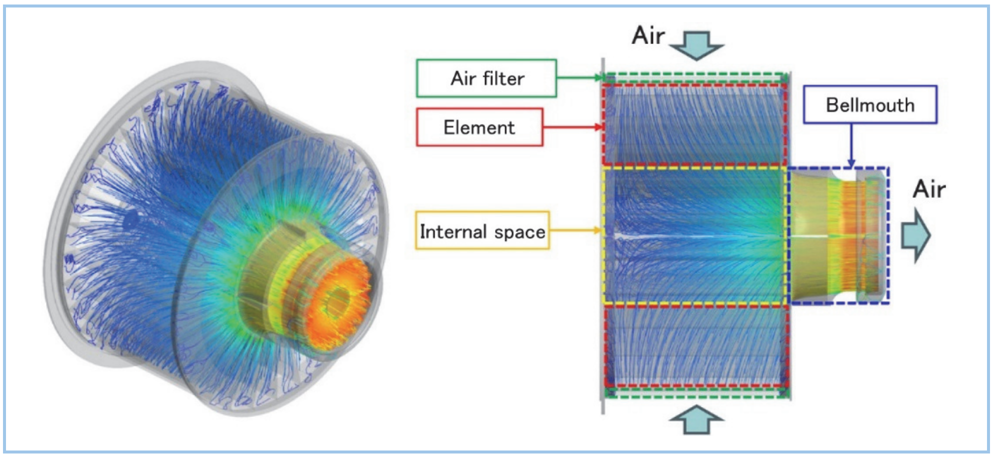

Figure 8 Silencer internal flow and division into multiple sections

6. Conclusion

To address the recent needs for marine turbochargers to achieve higher compressor pressure ratios and larger capacities while simultaneously meeting noise reduction requirements, and to respond to various product needs driven by future market expansion, technology for MET turbocharger silencer was established. Consequently, a path has been established toward achieving performance equivalent to current model, which was the objective initially set, while enabling the realization of well-balanced silencers that meet diverse needs using the design technology established. The application of this technology is expected to significantly contribute to enhancing product value. On the other hand, these results apply only to the size MET33, a target in this study, and the specification expansion to the other sizes and the validity of the design tools for such expansion remain unvalidated. Going forward, MHI will continue to pursue even higher performance and lower noise while also enhancing the design technology for the new silencer and improving the product value of MET turbochargers. Furthermore, the initiatives described in this report are not limited to applications in MET turbochargers but can be extended to various other products. MHI will continue to promote further enhancement of its technological capabilities, contributing to the further improvement of product value across the entire MHI Group.

References

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(2) Leo L. Beranek, Noise and Vibration Control, McGraw-Hill, (1971), p.383