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New Technology of MET Turbocharger toward Decarbonization

Turbochargers & Air/Exhaust Management

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ABSTRACT

The International Maritime Organization (IMO) has set targets for improving energy efficiency in international shipping, aiming for 40% or greater improvements from 2008 levels by 2030, and ultimately achieving zero greenhouse gas (GHG) emissions from international shipping by 2050. Meeting these targets requires the development and implementation of appropriate technologies.

To improve energy efficiency, it is necessary to reduce fuel consumption. One of the most effective ways is to implement stronger Miller cycle which requires the higher pressure ratio for turbocharger.

To achieve zero GHG emissions, the adoption of engines using fuels that do not emit CO2, such as ammonia fuel and hydrogen fuel, is expected to advance. Engine manufacturers are currently actively developing technologies related to these alternative fuels. The introduction of these new fuels may require higher pressure ratios for turbochargers, depending on the engine tuning.

Simultaneously, there is a demand for downsizing turbochargers to reduce CAPEX and OPEX, thus necessitating the establishment of model ranges that meet market needs. Increasing compressor capacity to meet this demand and turbine capacity to select appropriate turbines are also necessary. Additionally, turbocharger responsiveness needs to be improved to maintain engine’s transient response when applying turbochargers to marine auxiliaries.

This paper provides the latest information on MET turbochargers, with a focus on the most recent development updates on compressors and turbines.

1 INTRODUCTION

The International Maritime Organization (IMO) aims to improve energy efficiency in international shipping by 40% or more compared to 2008 levels by 2030, with the ultimate goal of achieving net-zero greenhouse gas (GHG) emissions by 2050.

To enhance energy efficiency, it is crucial to reduce fuel consumption. One of the most effective methods for achieving this is the implementation of the Miller cycle, which necessitates turbochargers with high pressure ratios.

To meet the net-zero GHG target by 2050, the adoption of alternative fuels that do not emit CO2, such as ammonia and hydrogen, is considered essential. Engine manufacturers are actively developing technologies related to these alternative fuels, which may require an increase in the pressure ratios and efficiency of turbochargers depending on engine tuning.

Simultaneously, there is a need to downsize turbochargers to reduce capital expenditure (CAPEX) and operational expenditure (OPEX), while also providing model ranges that align with market demands. Furthermore, improving the performance of compressors and turbines is necessary to meet these evolving market needs.

This paper summarizes the new technologies for MET turbochargers designed and manufactured by MHI-MME (Mitsubishi Heavy Industries Marine Machinery and Equipment) to comply with stricter environmental regulations, with a particular focus on the latest developments in compressors and turbines.

2 OVERVIEW OF MET TURBOCHARGER

Since the introduction of the completely non-cooled MET turbocharger to the market in 1965, we have developed new technologies and launched new series of turbochargers in response to various requirements from the engine sector. The MET turbochargers are classified into two groups: axial-type turbochargers and radial-type turbochargers. The axial-type group includes the MET-SD, SE, SEII, MA, MB, and MBII series (Figure 1), which are primarily applied to two-stroke engines. The radial-type group includes the MET-SR, SRII, SRC, and ER series (Figure 2), which are mainly used for four-stroke engines. By the end of 2024, the cumulative production of turbochargers from these two groups exceeded 46,000 units (Figure 3).

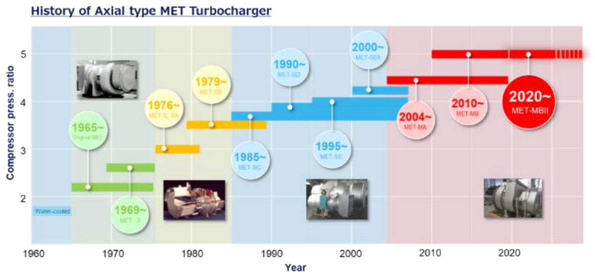

Figure 1. History of Axial type MET Turbochargers

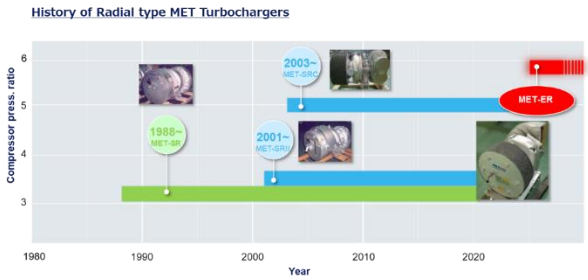

Figure 2. History of Radial type MET Turbochargers

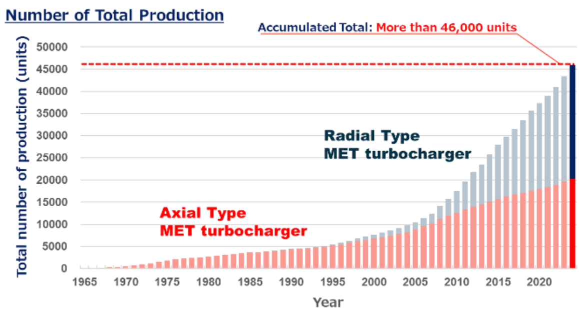

Figure 3. MET turbocharger total production volume

The latest addition to the axial-type turbocharger lineup is the MET-MBII series. Compared to the MET-MB series, this new turbocharger series not only features higher pressure ratios but also larger capacities, allowing a one-size-smaller model to cover a wider range, thus achieving downsizing of the turbocharger.

3 LATEST STATUS OF AXIAL-TYPE TURBOCHARGER FOR TWO-STROKE ENGINES

Table 1 and Table 2 present the status of MET axial-type turbochargers in relation to stricter environmental regulations.

Table 1. Status of applicability to various tunings and new fuels

	SCR		EGR		Dual Fuel
	HP	LP	HP	LP	
J-ENG (UE)		✔		✔	
MAN E&S	✔	✔	✔		✔ (ME-GI, GA, GIE, LGIP,LGIM,LGIA)
WinGD	✔	✔		✔ (iCER)	✔ (X-DF)
MET Turbocharger	Applicable	Applicable	Applicable	Applicable	Applicable

Table 2. Layout of turbocharger on engines equipped with EGR or SCR

SCR		EGR		
HP	LP	HP	LP	
				
 Axial type gas inlet casing is applied	No changes	Sequential turbocharging system is applied	Requires modification of silencer and application of coating to impeller or change to corrosion-resistant material	

Source : https://www.j-eng.co.jp/news/press/17.html, http://marine.man.eu/two-stroke/brochures, https://www.wingd.com/en/news-media/wingd-in-the-news/wingd-drastically-reduces-capex-with-first-on-engine-icer-order/

MET axial-type turbochargers are compatible with all high-pressure and low-pressure SCR/EGR engine specifications across various engine brands, including dual-fuel engines from both MAN ES and WinGD. The applicability of these turbochargers to alternative fuel engines is outlined below.

For methanol-fueled engines, we delivered MET90MB, the world's largest turbocharger, and MET60MBII, for MAN ES's 8G95ME-C10.5-LGIM-EGRTC HP-EGR engine. Engine tests confirmed that the required performance for Tier II mode (using MET90MB and MET60MBII), Tier II TCCO mode (using MET90MB only), and Tier III EGR mode were achieved. By 2024, we have received orders for 88 turbochargers for 41 units of ME-LGIM series engines (Figure 4).

Figure 4. ME-LGIM engine shop test status and order records

For ammonia-fueled engines, we delivered a MET66MBII turbocharger for MAN ES's 7S60ME-C10.5-LGIA-HPSCR engine, which is currently undergoing on-engine testing as of 2025. Additionally, a MET53MBII turbocharger is being prepared for delivery in 2025 for J-ENG's UEC50LSJA engine.

To adapt the MET turbocharger for ammonia-fueled engines, a risk assessment regarding ammonia slip has been conducted. Each component of the turbocharger was evaluated under the estimated operating environmental conditions. As a result, the materials for copper-based parts (such as thrust bearings and oil labyrinths) and rubber parts (such as O-rings) were modified to mitigate the risk of corrosion due to ammonia. Furthermore, the bearings were assessed for potential ammonia contamination in the lubricant (Figure 5).

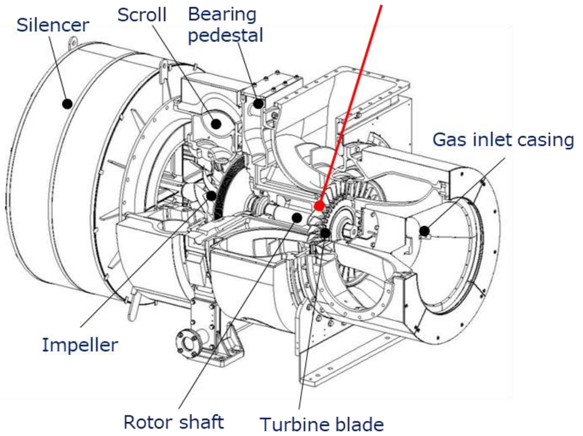

Figure 5. Turbocharger components changed for ammonia-fueled engine

For hydrogen-fueled engines, we are preparing to deliver a MET33MBII turbocharger in 2025 for J-ENG's UEC35LSGH DF hydrogen-fueled engine, with turbocharger specifications currently under discussion.

To apply the MET turbocharger to hydrogen-fueled engines, a risk evaluation concerning hydrogen attack and hydrogen embrittlement for each material has been conducted. For hydrogen attack, existing components were evaluated based on their material and operating temperature using the Nelson curve, confirming that the risk is low. For hydrogen embrittlement, each component was assessed based on material properties, strength, and operating temperature, following standards applicable to hydrogen pressure vessels, such as those set by EIGA. Components identified as having potentially high risks, such as the turbine wheel and gas inlet casing, underwent hydrogen embrittlement susceptibility test to confirm that the risk of hydrogen embrittlement is low.

4 LATEST STATUS OF RADIAL-TYPE TURBOCHARGER FOR FOUR-STROKE ENGINES

4.1 Requirements for turbochargers for energy efficiency improvement and GHG Reduction

First, to improve the energy efficiency of ships, employing the Miller cycle and increasing the average effective pressure are effective strategies for reducing engine fuel consumption. Turbochargers are required to have higher pressure ratios, along with high-efficiency and high-capacity turbines, to minimize pumping losses.

Next, for greenhouse gas (GHG) reduction, engines that utilize alternative fuels (such as ammonia and hydrogen) in premixed combustion require precise air-fuel ratio control to prevent engine misfire, incomplete combustion, and knocking. Consequently, turbochargers must exhibit a faster transient response compared to those operating with conventional fuels, necessitating a reduction in rotor inertia and an improvement in turbine efficiency.

Additionally, it is anticipated that alternative fuel engines will operate in dual-fuel mode alongside heavy oil. In dual-fuel operation, the ancillary equipment of the engine, such as fuel piping, increases, thereby reducing the available space for installing a turbocharger. As a result, turbochargers must be more compact.

For other requirements related to the use of alternative fuels, a conceptual examination was conducted based on publicly available data. To clarify the operating conditions required for turbochargers when fuel is converted to hydrogen or ammonia, we simulated a marine four-stroke auxiliary engine to estimate performance.

In the calculations, the engine output and turbocharger efficiency were assumed to be fixed and constant, respectively. We calculated the appropriate λ (lambda) that maximized thermal efficiency while keeping the turbocharger gas inlet temperature, Pmax, knocking intensity, and NOx emissions within specified limits. Using this λ value, we evaluated the differences in turbocharger operating conditions compared to the LNG-fueled base engine.

For hydrogen fuel engines, calculations were conducted with a 20% reduction in compression ratio, as hydrogen fuel makes high-load operation challenging due to knocking. Most four-stroke auxiliary engines using ammonia or hydrogen fuel are of the premixed combustion type (Otto cycle), so the simulations were performed using the premixed combustion method. The pilot percentage of ammonia fuel was set at 30 cal%. For the examination results, see Figure 6. Due to the low combustibility of NH_3, achieving a lean burn is difficult. Thermal efficiency reaches its maximum when λ is approximately 1.2, but deteriorates drastically when λ exceeds 1.8. However, current exhaust temperature limitations necessitate a certain degree of leaner burning. It is assumed that λ will be around 1.4 to 1.6 during actual operation under current specifications; however, thermal efficiency deteriorates by more than 15% compared to LNG-DF.

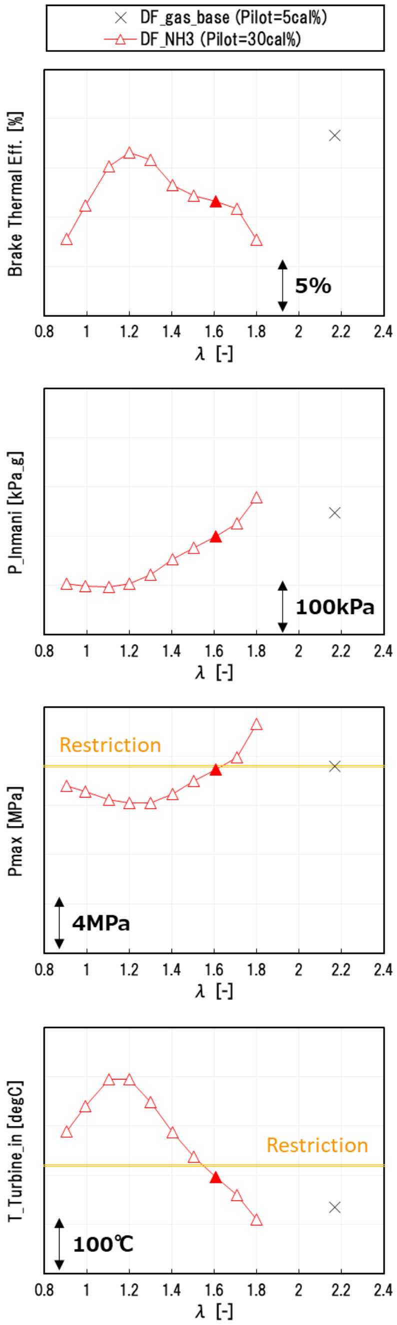

Figure 6. Primary evaluation using engine simulation (NH3)

From the above examination, it is evident that, especially for ammonia, a reduction in heat load is necessary, which in turn requires improvements in turbocharger efficiency.

The pilot percentage of hydrogen fuel was set at 5 cal%, the same as for the base LNG-DF. For the examination results, see Figure 7. Due to the high combustibility of H_2, thermal efficiency improves even when the mixture is leaned out to increase λ to around 3.0. However, thermal efficiency is about 5% lower than that of LNG-DF because combustion timing cannot be advanced sufficiently due to knocking, and the pressure ratio is reduced. Considering NOx emissions and Pmax, the appropriate λ for current specifications is about 2.4.

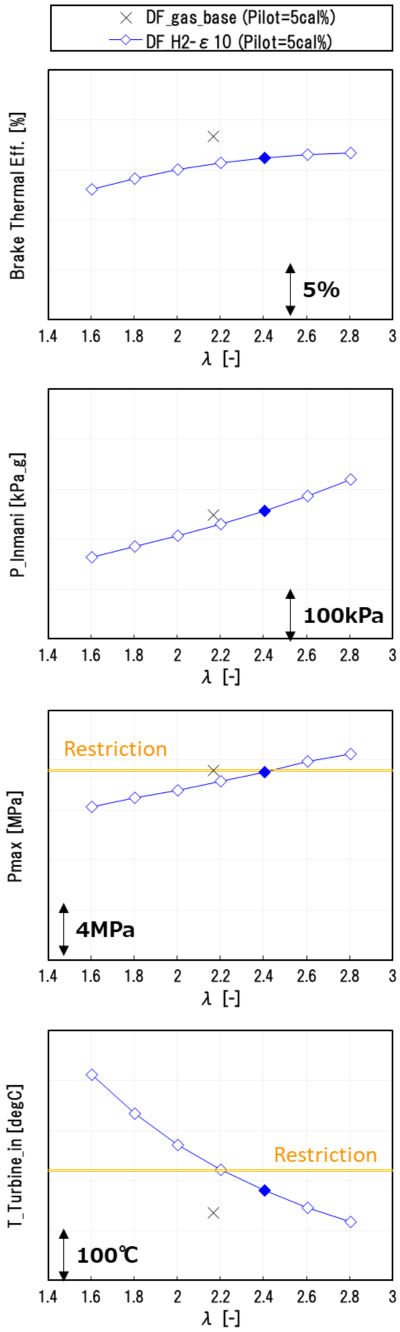

Figure 7. Primary evaluation using engine simulation (H2)

While this depends on the Pmax restrictions on the engine side, it is highly likely that turbochargers will need to have higher pressure ratios to address NOx-related issues and improve thermal efficiency when operating with hydrogen fuel. Additionally, the ongoing need to reduce CAPEX and OPEX requires turbochargers to be more compact while also accommodating larger flow capacities.

4.2 Development of compressor and turbine to meet requirements from engine side

This section discusses the development status of compressors and turbines for radial-type turbochargers that meet the requirements from the engine side, as described in Section 3, in order to comply with stricter environmental regulations.

First, the status of compressor development is as follows. We have created an impeller using design optimization to achieve a higher pressure ratio. At the prototyping stage, we have successfully developed an impeller that attains a pressure ratio of 6.0, and we are currently conducting verification tests with the aim of adding this compressor to our product lineup.

The process of implementing design optimization is illustrated below (Figure 8): We select initial designs from the design space based on Latin Hypercube Sampling (LHS), create a response surface for the objective function, solve the optimization problem based on the created response surface, and perform multiple iterations of individual searches to obtain the optimal shape while improving model accuracy. We employed the multi-start gradient method for the individual search and Kriging for the response surface model to facilitate efficient searching while accounting for model uncertainty.

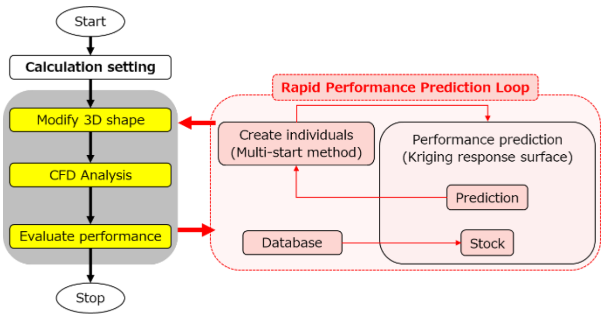

Figure 8. Optimization design implementation process

The procedure for designing compressors using optimization is as follows: First, we parameterize the full blade shape and splitter blade shape, set upper and lower limit values for each parameter, and implement design optimization (Figure 9). Next, we conduct multiple optimization calculations and, along with the database, perform shape and flow analysis of multiple designs (Figure 10). Finally, from the optimization-calculated designs, we extract the individual that is expected to show improved performance compared to the base shape and analyze it in detail (Figure 11).

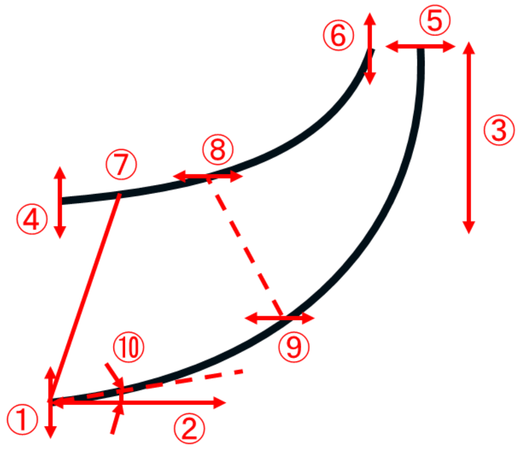

Figure 9. Example of compressor parameters for optimization

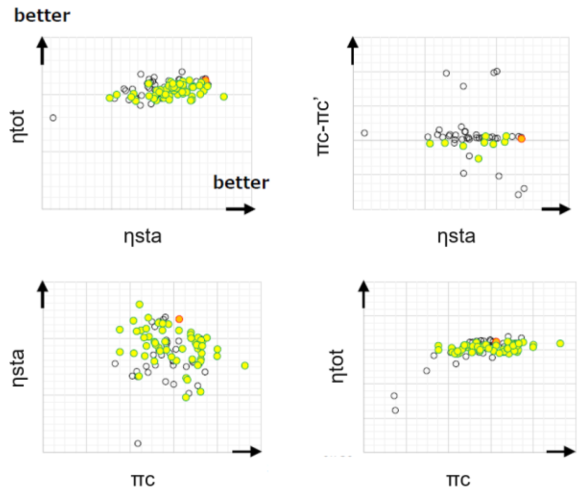

Figure 10. Flow analysis for optimized design individuals

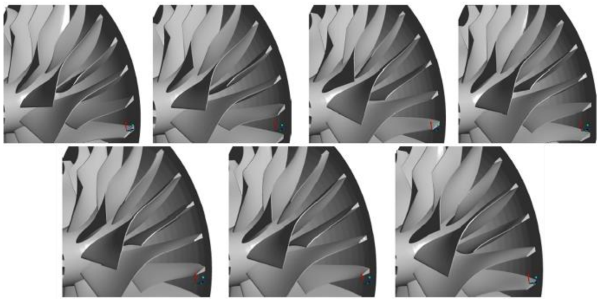

Figure 11. Extract compressor blade shape by optimized design

Figures 12 and 13 compare the analysis results of the internal flow before and after the optimization design, indicating that the slower-flow region was reduced following the optimization. It was confirmed that the improvement in internal flow increased the compressor efficiency by approximately 2%pt at a pressure ratio of around 5.5 compared to the base shape.

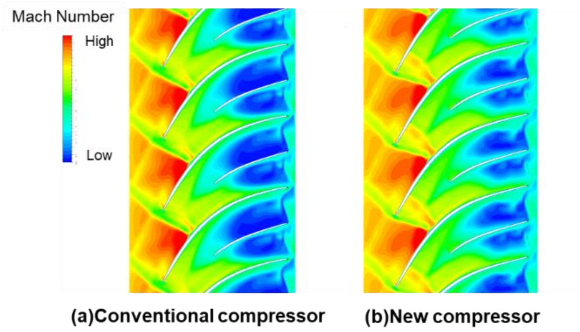

Figure 12. Comparison of internal flow before and after optimum design

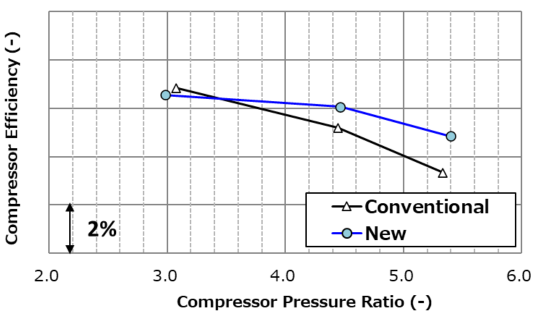

Figure 13. Comparison of compressor efficiency before and after optimum design

Figure 14 and 15 compares the airflow and performance between the conventional impeller for MET-SRC and the optimized design impeller generated after repeating the aforementioned design optimization and performance verification tests. The optimized design achieved an increased pressure ratio and improved performance on the high-pressure ratio side while maintaining the same airflow rate.

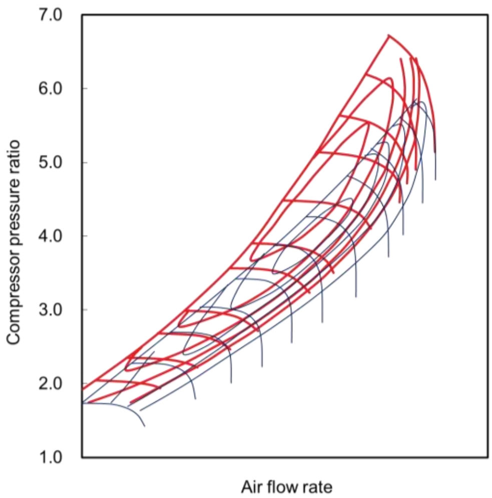

Figure 14. Comparison of airflow between optimization-designed impeller and conventional impeller for MET-SRC

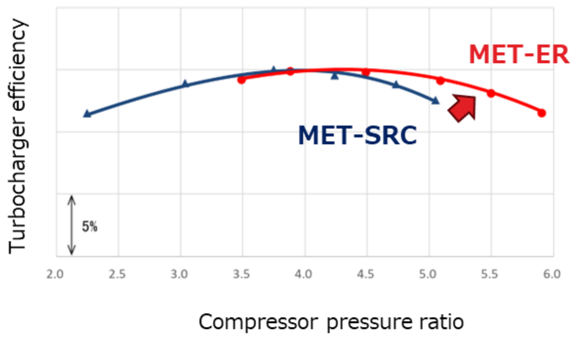

Figure 15. Comparison of performance between optimization-designed impeller and conventional impeller for MET-SRC

Next, the status of turbine development is as follows. We are developing large-capacity, high-efficiency turbines with the aim of reducing pumping loss and rotor inertia, thereby improving turbocharger efficiency and making turbochargers more compact. We developed a new large-capacity turbine that achieves both aerodynamic performance and structural strength by understanding the aerodynamic performance of each component and its sensitivity to blade vibration strength in advance, and by optimizing the combination among them. Simultaneously, the scallop shape, which has been applied since the MET-SRC, was optimized while confirming the balance between performance and rotor inertia (Figure 16).

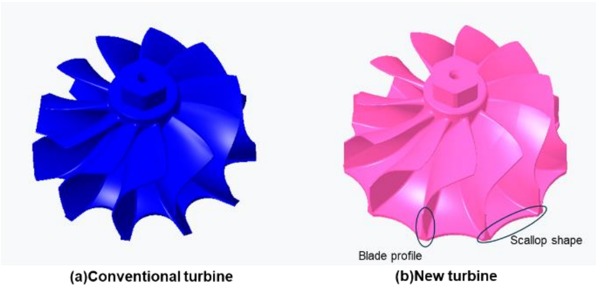

Figure 16. Improvements of new turbine wheel compared to conventional type

As shown in Figure 17, by applying the developed turbine wheel, we achieved approximately 7% higher capacity compared to the MET-SRC wheel of the same diameter. Additionally, the gas outlet casing downstream of the turbine wheel was optimized for gas flow from the large-capacity turbine. Its cross-sectional shape was adjusted to eliminate separation areas and restore pressure, thereby improving turbine efficiency. Analysis confirmed that this shape significantly improves Cp compared to the conventionally applied casing shape and increases turbine efficiency by approximately 5 %pt at a turbine pressure ratio of 4.5 (Figures 18 and 19).

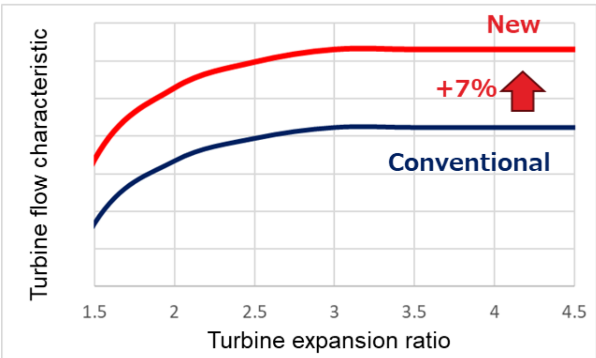

Figure 17. Comparison of turbine flow characteristic conventional and new turbine wheel

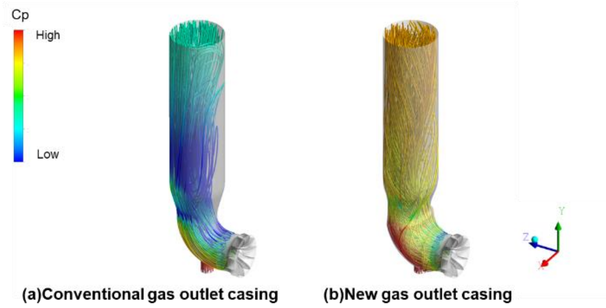

Figure 18. Comparison of internal flow conventional and new gas outlet casing

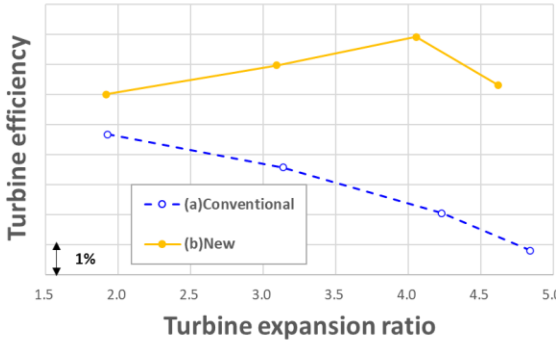

Figure 19. Comparison of turbine efficiency conventional and new gas outlet casing

For downsizing turbochargers, the newly developed radial-type turbocharger MET-ER has been reduced in size by about 40% compared to the MET-SRC series by optimizing the flow path shape of the casing and reviewing the internal structure, in addition to reducing the rotor diameter due to the newly developed large-capacity turbine wheel (Figure 20).

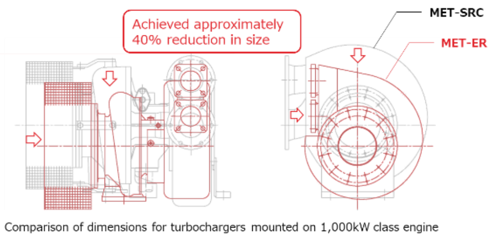

Figure 20. Comparison of dimensions for turbochargers mounted on 1,000kW class engine

5 CONCLUSIONS

In response to environmental regulations in international shipping and the movement towards reducing greenhouse gas (GHG) emissions, turbochargers play a significant role as they greatly influence the combustion of alternative fuels in engines.

To address the increasing demands for turbochargers in recent years, MHI-MME has been simultaneously developing new technologies, including compressors with high pressure ratios and large-capacity turbines, to meet the required specifications for both two-stroke and four-stroke engines. This development process incorporates technologies such as design optimization and engine simulation.

MHI-MME will continue to contribute to global environmental conservation through its turbocharger innovations and will strive for technological advancement and functional improvements to meet the increasingly diverse needs of our customers.

6 REFERENCES AND BIBLIOGRAPHY

[1] Yoshikazu Ito. 2019. Development of New-Generation MET Turbocharger, CIMAC Congress Paper No. 259

[2] Yushi Ono. 2019. Development of New Radial Turbocharger MET-ER Series, CIMAC Congress Paper No. 386

[3] Yushi Ono. 2023. Status of MET turbochargers for alternative fuels to reduce GHG emissions, CIMAC Congress Paper No. 96