

Optimization of turbocharger performance on MV Magnanimous through planned maintenance under the Total Productive Maintenance (TPM) framework

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Abstract

The turbocharger is a critical component of marine diesel engines, playing a vital role in enhancing air intake pressure and combustion efficiency. This study aims to evaluate the performance degradation of the turbocharger installed on the main engine of Vessel Magnanimous and to implement a structured maintenance strategy to restore its functionality. The research adopts a field-based Research and Development (R&D) approach over a 14-month marine engineering practice period. Primary data were obtained through direct observation, operational logbooks, and technical inspections before and after the overhaul and air filter cleaning procedures. The results show a significant performance recovery: exhaust gas temperature increased from 440/400°C to 450/420°C, scavenge air pressure rose from 0.18 MPa to 0.27 MPa, and turbo blower speed returned to 25000 rpm. These improvements reflect the effectiveness of planned maintenance, a core pillar of the Total Productive Maintenance (TPM) framework. Moreover, the restored turbocharger performance contributed to improved combustion efficiency and system reliability, supporting the vessel's operational productivity. The study concludes that integrating technical repair with TPM-based maintenance can enhance the overall effectiveness of marine engine systems.

Keywords:

Turbocharger, performance restoration, planned maintenance, TPM, MV Magnanimous

1 Introduction

The turbocharger is an important device in a diesel engine combustion system, which functions to increase the intake air pressure through a compression process. The atmospheric air entering the compressor is compressed by a rotor driven by a turbine through a connecting shaft. The turbine gains energy from the engine's exhaust gases, allowing the pressurized air to enter the combustion chamber to improve combustion efficiency.

In a diesel engine, the rotation of the turbocharger is driven by the exhaust gas pressure from the combustion chamber before it is expelled through the exhaust. Regular maintenance of its components is needed to maintain the optimal performance of the turbocharger continuously. One very crucial component is the turbine blades, which must be kept clean to avoid disrupting the rotation and exhaust gas pressure.

According to [1][2], the turbocharger consists of a gas turbine unit and a compressor unit connected on a single shaft, where the turbine rotates the compressor by utilizing energy from the exhaust gas. Disruptions such as carbon soot accumulation and dirty air filters can significantly reduce the performance of this system.

A turbocharger is a machine that can produce compressed air of more than 1 atm, which is essential for the combustion process of fuel in the cylinder. In a diesel engine, the turbocharger's rotation is driven by the exhaust gas pressure from within the cylinder before it exits to the exhaust pipe. Therefore, the rotation of the turbocharger needs to be maintained to ensure that the turbocharger's performance remains continuously optimal. One of the things that must be maintained is the maintenance of its components, especially on the turbine blades, which should always be cared for to keep their rotation optimal and the gas pressure from decreasing.

The turbocharger maintenance strategy carried out in this research can be reviewed as part of the Total Productive Maintenance (TPM) approach. TPM is a comprehensive maintenance system aimed at maximizing equipment effectiveness through the elimination of losses, engaging all personnel, and implementing scheduled maintenance.

One of the main pillars of TPM is planned maintenance, which is routine machine maintenance activities to prevent sudden breakdowns and extend the lifespan of equipment [3][4]. Thus, the overhaul and periodic cleaning actions conducted in this study can be categorized as TPM practices that support operational reliability and the sustainable productivity of the machine system.

This research aims to analyze the relationship between exhaust gas temperature changes and turbocharger rotation, as well as the influence of outside air conditions on compressor performance. Theoretically, this study is expected to expand knowledge about turbocharging systems in main engines and serve as a reference for further researchers who will discuss turbochargers. Practically, it is hoped to provide references for companies as well as land and maritime transport vehicles powered by diesel engines that have turbocharging systems, especially for engineers working on ships as officers, and also for those in land transportation working as mechanics related to propulsion engines that have turbocharging systems. The primary focus of the study is to identify the causes of suboptimal turbocharger performance and evaluate the improvement efforts implemented on the main engine of the Vessel Magnanimous ship.

2 Research methodology

2.1 Material and data

This research employs a Research and Development (R&D) approach aimed at maintaining and restoring the optimal performance of the turbocharger on the main engine of the Vessel Magnanimous [5]. The R&D approach is utilized because it allows researchers to directly identify problems, design solutions, and test the effectiveness of corrective actions in real operational conditions on the ship [6].

The research was conducted during the sea practice activities (prala) on the Vessel Magnanimous ship for 1 year, 2 months, and 3 days (September 9, 2022 – November 11, 2023). The data collection process was carried out in the engine room through direct observation, technical interviews with the engineers and the chief engineer, and documentation of operational data from the log book and the turbocharger manual book [1][7].

Primary data was obtained through direct observation of exhaust gas temperature, scavenge air pressure, turbo blower rotation, and turbocharger overhaul results [8]. Secondary data was obtained through technical literature, textbooks, and documentation from manufacturers and shipping companies [9][10].

2.2 Stage of the study

The flow of the research implementation is described in Fig. 1, which includes the following stages:

1. Problem identification: The decline in turbocharger performance due to carbon buildup on the turbine blades and a dirty air filter [7];
2. Cause analysis: Evaluation of the impact of temperature, pressure, and engine speed on turbocharger performance [11];

3. Repair actions: Overhaul, cleaning components using a carbon cleaner, and measuring turbocharger clearance [1]; and
4. Result evaluation: Comparison of parameters before and after repairs. Conclusions and recommendations for preventive maintenance [1].

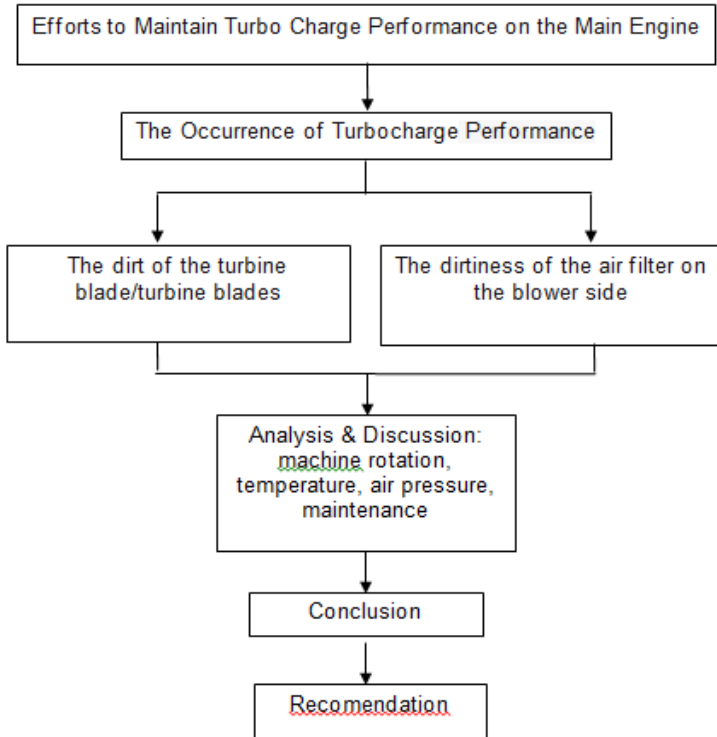


Fig. 1. Stage of the study

2.3 Data Analysis

The method used is qualitative descriptive analysis, which involves describing the relationships between variables, such as exhaust gas temperature, air pressure, and turbo blower rotation, based on observation data before and after maintenance actions. In addition, a problem cause identification is also conducted using the Man, Money, Material, Method, Machine, Market, and Environment (6M + 1E) approach as a reference for analyzing the factors causing the decline in turbocharger performance [12]

The analysis aims to explain how maintenance actions can effectively restore turbocharger efficiency in the field. The overhaul and cleaning strategies in this study are categorized as a form of planned maintenance, which is one of the main pillars in the TPM approach to achieve sustainable equipment effectiveness [4] [13].

2.3.1 Calculation formula

To support the technical analysis in this research, several relevant basic calculation formulas related to turbocharger performance and maintenance impact are used. These formulas are used to compare parameters before and after maintenance actions, as well as to evaluate the system's effectiveness quantitatively.

2.3.1.1 Pressure ratio [14]

The pressure ratio can be calculated using Eq. (1), where P_{out} is the air pressure out of the compressor (scavenge) and P_{in} is the air pressure entering the compressor.

$$PR = \frac{P_{out}}{P_{in}} \quad (1)$$

2.3.1.2 Presentation on performance improvement

The extent to which the values of technical parameters such as exhaust gas pressure, temperature, and turbo speed can be increased can be calculated using Eq. (2) [15].

$$\%Improvement = \frac{X_{after} - X_{before}}{X_{before}} \times 100\% \quad (2)$$

2.3.1.3 OEE context in TPM

Conceptually, the effectiveness of the system after maintenance can be associated with Overall Equipment Effectiveness (OEE), a key pillar of TPM that measures equipment performance through three components: Availability, Performance, and Quality (Eq. (3)) [13].

$$OEE = Availability \times Performance \times Quality \quad (3)$$

OEE is often used in industrial TPM to monitor and improve equipment productivity by analyzing losses. Although not explicitly calculated in this article, the planned maintenance structure is aligned with the practices of improving Availability and Performance in TPM. Studies [13][16] establish OEE as a key parameter in TPM evaluation.

3 Results and discussion

3.1 Result

3.1.1 Technical specification from the main machine and turbocharger

Specifications for the turbocharger of the main engine of the ship type AHTS are detailed as follows: Dead Weight (DWT) of 1396.74 tons, Gross Tonnage (GT) of 1075, Net Tonnage (NT) of 352, Length Overall (LOA) of 59.2 M with a Breadth (B) of 13.8 M. Illustration of the turbocharger is shown in Fig. 2 and Table 1. The ABB VTR254-21 turbocharger specifications can be seen in Table 2.



Fig. 2. Turbocharge Holset model
Source: Engine room MV. magnanimous

Table 1. Main machine specifications

Parameter	Value
Type of engine	Diesel DEUTZ (2 set)
Year of manufacture	2003
Country of origin	USA
Number of cylinders	9
Serial number	33175247(PS)/33175582(SB)
Max output	895 kW @ 1800 rpm
Idle speed	625–700 rpm
Max RPM	1800 rpm
Horse power	2 × 2750 HP

Table 2. Specifications of turbocharger ABB VTR254-21

Parameter	Value
Type	VTR254-21
Fabrication	ABB
Max RPM	25.000 rpm
Standard inlet pressure	0.6 – 1.7 kgf/cm ²
Standard inlet temperature	450°C

The observations show that exhaust gas temperatures T_1 and T_2 are 440°C and 400°C, respectively, while the intake air pressure only

reaches 0.18 MPa. The turbo blower speed also decreased to 22500 rpm from the standard 25000 rpm (Table 3 and Fig. 3). This indicates a disturbance in the suction efficiency and the exhaust gas expansion process.

Table 3. Performance parameters of the turbocharger before repair

Parameter	Value	Standard
Temperatur exh (T_1/T_2)	440/400°C	450/420°C
Blower rotation	22500 rpm	25000 rpm
Scavenge pressure (P_1)	0.18 MPa	0.27 MPa
Air temperature ($T_3/T_4/T_5$)	28/68/45°C	Stable

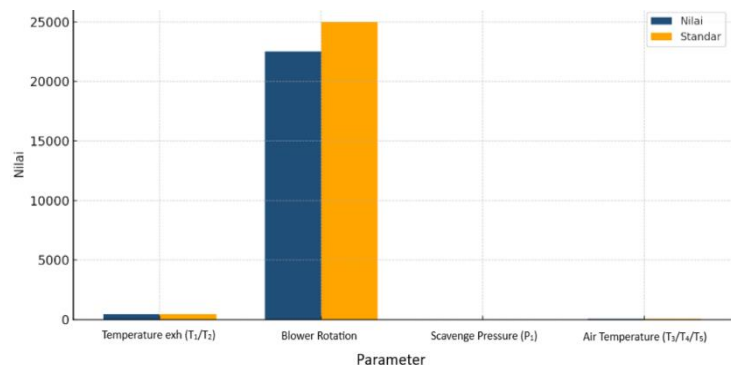


Fig. 3. Comparison of performance parameters of the turbocharger before repair with stable

This decline is believed to be strongly caused by the accumulation of carbon deposits on turbine blades and the dirtiness of the air filter. This is consistent with the findings [7], which states that irregular overhauls and a lack of maintenance of the air system lead to a decrease in turbocharger performance.

3.1.2 Evaluation of overhaul and cleaning results

The maintenance actions taken include an overhaul of the turbocharger and a thorough cleaning of the air filter on the blower side. The overhaul activity was carried out by disassembling the compressor and turbine housing, cleaning carbon deposits on turbine blades using carbon cleaner and compressed air at 7.5 kg/cm², as well as measuring the gap (clearance) between turbine and housing using a feeler gauge.

Inspection of the physical condition of components showed that turbine blades had significant carbon soot buildup, and the air filter was dirty and dark in color. Cleaning was carried out by soaking the air filter in diesel, rewashing it with water and detergent, and then drying and respraying it with compressed air. Based on the results of the formula analysis, it is proven that the air entering the compressor is compressed, increasing pressure and temperature. In contrast, during the process that occurs in the turbine, the combustion gas expands within the gas turbine, causing the turbine blades to rotate along with the same shaft that drives the compressor, resulting in a decrease in pressure and temperature due to the expansion process.

After the cleaning and reassembly process, engine testing was carried out for approximately two hours to ensure that system performance had returned to normal. The test results showed no leaks of lubricant or coolant, turbocharger rotation is stable again and free from vibrations, and the combustion system generates increased exhaust gas temperature and pressure to meet manufacturer standards. So, through this analysis, it is proven that the performance of the turbocharger occurs in two processes with two main components. It is also influenced by the temperature and pressure of the exhaust gas; when the temperature is high, the pressure of the exhaust gas is also high. However, the exhaust gas contains carbon deposits that adhere to the turbine blades, which gradually thicken, and this impact imposes a load on the turbine expansion chamber.

In addition, the measurement results of clearance (Fig. 4) also show conformity with the technical specifications, which consist of clearance of the blower with housing of 0.30 mm and clearance of the turbine with housing of 0.25 mm. This value is within the allowed

limits according to the technical manual of the ABB VTR254-21 turbocharger.



Fig. 4. Result of turbocharger clearance measurement

From the perspective of TPM, the actions of overhauling and cleaning the turbocharger components in this study reflect the implementation of the Planned Maintenance pillar, which involves scheduled maintenance activities to prevent failures and ensure system reliability [17].

By systematically conducting an overhaul, carbon buildup on the turbine blades can be prevented earlier, keeping the turbocharger's performance optimal and stable. In addition, findings that indicate a decrease in pressure and blower rotation before maintenance form the basis for the implementation of Focused Improvement, which is a targeted improvement activity at specific points of efficiency losses.

Through the combination of these two pillars of TPM, the effectiveness of the ship machinery system can be continuously improved [17][18]. The implementation of planned maintenance in the manufacturing industry has proven capable of reducing machine downtime and significantly increasing production effectiveness, as demonstrated by similar research in the industrial sector [17].

This finding proves that overhaul procedures and regular maintenance significantly affect the reliability of the turbocharger. Without these actions, the decline in pressure and operating temperature will continue, negatively impacting the performance of the main engine.

3.1.3 The impact of maintenance on turbocharger performance

After the overhaul and cleaning of the air filter, there was an improvement in the technical parameters. The exhaust gas temperature rose to 450°C, and the air pressure increased to 0.27 MPa. Blower speed approached 25000 rpm again (Table 4 and Fig. 5).

Table 4. Comparison of turbocharger performance before and after repair

Parameter	Before	After	Standard
Temperature exh (T_1/T_2)	440 / 400°C	450 / 420°C	450 / 420°C
Blower rotation	22.500 rpm	~25.000 rpm	25.000 rpm
Scavenge pressure (P_1)	0,18 MPa	0,27 MPa	0,27 MPa
Air temperature $T_3/T_4/T_5$	28 / 68 / 45°C	28 / 65 / 45°C	Stable

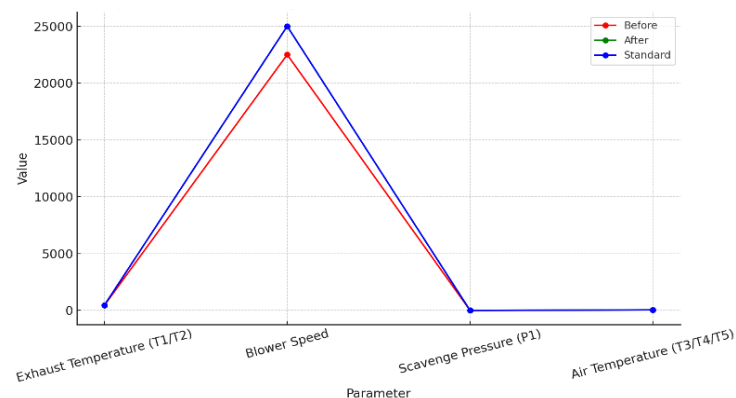


Fig. 5. Comparison of performance parameters: turbocharger before and after repair

This improvement demonstrates the effectiveness of overhauls and periodic cleaning in maintaining system efficiency, as explained by [19] that the efficiency of a turbocharger is highly dependent on the cleanliness of turbine components and the quality of incoming air.

3.2 Discussion

The results obtained in this study are consistent with previous studies by [1][7], which states that carbon deposits and delayed overhauls generally cause a decline in turbocharger performance. According to maintenance standards for turbochargers issued by ABB and technical reference [19], it is recommended to perform an overhaul every 10000–15000 working hours or at least every 2 years, depending on operational conditions. In this case, the MV Magnanimous ship only underwent an overhaul after 3 years, exceeding the ideal time threshold.

Carbon buildup on the turbine blades reduces the cross-sectional area of the exhaust gas flow, which hinders the kinetic energy from rotating the turbine [20][21]. Meanwhile, a dirty air filter causes a decrease in volume and pressure of air entering the compressor, resulting in low scavenge air pressure [21].

In addition, the relationship between the temperature and pressure of exhaust gas is significant for combustion efficiency. According to [19], every decrease of 50°C in exhaust gas temperature without adjustment will reduce the expansion pressure by about 10-12%, which directly affects the suction power of the blower.

Thus, the observation and analysis results show that: Technical parameters (RPM, pressure, temperature) improved after maintenance actions; The identified technical causes align with prior study findings; and Timely preventive maintenance plays an important role in maintaining the optimal performance of the turbocharger.

Furthermore, timely and structured turbocharger maintenance not only restores technical parameters to operational standards but also contributes directly to the effectiveness of the ship's machinery system as a whole. An optimally functioning turbocharger will enhance combustion efficiency, reduce fuel consumption, and minimize exhaust emissions, with its performance significantly influenced by variations in operational conditions of the engine [8][21].

This directly impacts the productivity of the ship, as the engine can operate at maximum performance without interruptions or loss of power. In the context of operational management of shipping, the successful maintenance of critical components such as turbochargers becomes an important factor in maintaining timely deliveries, fuel cost efficiency, and compliance with safety and environmental standards in shipping [17][22].

4 Conclusions

This study confirms that the decline in turbocharger performance on MV Magnanimous was primarily caused by carbon deposits on turbine blades and clogging of the blower air filter, which led to reductions in scavenge air pressure and turbo blower rotational speed. Through targeted maintenance actions, which specifically overhauled the turbocharger and thoroughly cleaned the air filter, key technical parameters were almost fully restored. Exhaust gas temperature increased to 450 °C, scavenge pressure improved to 0.27 MPa, and turbo blower speed stabilized at around 25,000 rpm, which reflects near-standard operating conditions. The results highlight the importance of implementing structured maintenance routines that combine preventive inspection, timely cleaning, and periodic overhauls. Integrating these measures into the TPM framework not only improves combustion efficiency and system reliability but also contributes to greater operational continuity of marine engines. This proactive approach ensures that turbocharger performance remains optimized over time, reduces the risk of costly failures, and supports sustainable vessel productivity.

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