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Article

Analysis of the Decrease in Compressed Air Production of the Air Compressor onboard MT Seroja III

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A B S T R A C T

The air compressor is an essential auxiliary machinery onboard MT Seroja III, playing a critical role in supporting vessel maneuverability, operational safety, and main engine starting readiness. During operations, a critical reduction in compressed air production was encountered, leading to prolonged air reservoir filling times and potential risks during ship maneuvering. This study aims to identify the root causes of decreased compressed air production in the main air compressor onboard MT Seroja III and to formulate corrective and preventive maintenance actions based on onboard observations and Fault Tree Analysis (FTA). This research employs a qualitative descriptive method, utilizing continuous monitoring parameter logs, field inspections, and semi-structured interviews with engine officers over a 12-month sea service period. The diagnostic findings using FTA indicate that the decrease in volumetric efficiency was primarily caused by high-resistance suction filter blockages, severe carbon fouling on suction and delivery valves, and piston ring degradation. Corrective maintenance involving filter purging, valve refacing, and piston ring replacement successfully restored the compressor discharge pressure to 30 bar and reduced the air receiver filling time from 45 minutes to 15 minutes. The study concludes that strict adherence to the vessel's Planned Maintenance System (PMS) is mandatory to guarantee operational safety and prevent compression loss.

1. Introduction

The shipping sector, serving as the backbone of international trade, plays a critical role in global economics by providing large-scale maritime logistics. Achieving optimal maritime operations requires an absolute synergy between seaworthy vessels and a highly competent engine room workforce. For tankers carrying liquid bulk cargoes, implementing a rigorous planned maintenance system for auxiliary machinery is fundamental to preventing operational delays and ensuring vessel maneuverability.

Among these auxiliary units, the main air compressor serves a critical function by generating the high-pressure air—typically stored between 25 and 30 bar—necessary for initiating the internal combustion starting air cycle of the main engine and auxiliary diesel generators. International maritime regulations mandate that the air reservoir capacity must sustain a specific number of consecutive engine starts without recharging, making compressor readiness directly tied to operational safety

The operation of marine main propulsion units, specifically internal combustion diesel engines, is fundamentally dependent on a reliable starting air system that utilizes high-pressure air—typically stored between 25 and 30 bar—to initiate the combustion cycle. This system must adhere to strict maritime regulations, which mandate sufficient air reservoir capacity to perform a specific number of consecutive starts, such as twelve for direct-drive engines, without the need for recharging (International Maritime Organization, 1974). Consequently, the air compressor serves as a critical auxiliary component; its consistent performance is vital not only for starting the main engine but also for supplying pneumatic equipment, necessitating a rigorous regime of planned maintenance to prevent mechanical failure and ensure the vessel’s continuous seaworthiness. Steam Turbine Main Propulsion Engines discusses the components and workings of steam turbines on ships' main propulsion engines in a comprehensive and systematic manner. The material is structured based on the competencies required by the Standard Training Certification of Watchkeeping for Seafarers (STCW) Manila Amendment 2010 (Abdi Seno, 2018)

Prior research by Muktar (2020) indicated that compressor degradation is frequently driven by thermal stress and carbon deposits on internal components. Onboard MT Seroja III, serious operational symptoms were observed, including an increase in air receiver filling time from 15 to 45 minutes, elevated operating temperatures exceeding 85°C, delayed pressure build-up, and continuous running behavior that caused severe mechanical overheating. This failure compromised the vessel's responsiveness during berthing and maneuvering operations.

While general compressor maintenance is widely documented, there is a lack of localized case studies combining technical parameter tracking with formal qualitative mapping to isolate dominant failure nodes under a ship's Planned Maintenance System (PMS). Therefore, this study aims to identify the root causes of decreased compressed air production in the main air compressor onboard MT Seroja III and to formulate focused corrective and preventive maintenance actions based on onboard observations and Fault Tree Analysis (FTA).

2. Literature Review

2.1 Marine Air Compressors and Performance Indicators

Marine air compressors operate on a reciprocating thermodynamic cycle where atmospheric air is drawn into a cylinder and compressed by a piston to generate high pressure. To accurately diagnose a drop in compressed air production, several engineering indicators must be monitored:

Discharge Pressure and Filling Time: The ultimate measure of compressor health; drop in pressure build-up rate directly extends the air receiver charging time.

Volumetric Efficiency: The ratio of actual air delivered to the displacement volume of the cylinder. Blockages or thermal variations directly compromise this parameter.

Operating Temperature: Excessive cylinder or discharge manifold temperatures indicate internal re-compression or friction.

2.2 Degradation Mechanisms of Compressor

1. SubsystemsSuction Filtration System: The suction filter isolates environmental particulates and oil mist. Particulate saturation restricts ambient airflow, creates high intake resistance, lowers the mass flow rate, and decreases volumetric efficiency.

2. Suction and Delivery Valves: High operating temperatures crack the entrained lubricant, leading to carbonaceous deposits on the valve seats. Carbon fouling prevents tight valve seating, causing compressed air backflow, delayed pressure delivery, and compression loss.

3. Piston Rings and Cylinder Liners: Reciprocating motion induces abrasive and tribological wear on piston rings, gradually widening the ring clearance gap. This wear destroys the airtight cylinder seal, causing a blow-by phenomenon where high-pressure air escapes back into the crankcase, inducing severe compression loss and abnormal oil consumption.

2.3 Lubrication and System Protection

Lubrication reduces mechanical wear at high-friction interfaces like pistons, cylinders, and bearings while dissipating generated heat. However, lubricating oil quality must be stringently managed; oil degradation or fluid carryover accelerates carbon deposit formations on discharge valve plates. Additionally, system safety relies on automated protective devices, including relief valves to prevent receiver over-pressurization and real-time pressure gauges to detect operational anomalies.

3. Research Methodology

This study utilizes a qualitative descriptive approach integrated with Root Cause Analysis (RCA) through the systematic mapping of Fault Tree Analysis (FTA). The research window spans a 12-month sea service period from August 2023 to August 2024 onboard MT Seroja III.

Primary data was gathered through field observation procedures and technical log assessments. Operational parameters—specifically discharge pressure, filling times, cylinder head temperatures, and running behaviors—were monitored at a frequency of twice per watch during active compressor cycles. Data validation was complemented by semi-structured interviews conducted over a one-week period in June 2024. The interview participants included the Chief Engineer and the Third Engineer, focusing on historical maintenance logs, valve clearance specs, and symptoms of pressure drops. Secondary data was synthesized from the manufacturer's technical instruction manual and historical maintenance archives.

The diagnostic mapping was executed using standard qualitative Fault Tree Analysis (FTA) layout protocols. The logic gates were structured around a singular focal point:

1. **Top Event:** "Decreased production of compressed air in the air compressor at MT Seroja III".
2. **Intermediate Events:** Linked via OR logic gates, representing visible symptoms including intake airflow restriction, safety valve noise, and low pressure-gauge readings.
3. **Basic Events:** The root physical failures terminating each causal branch, validated directly against physical onboard inspection data.

4. Results and Discussion

4.1 Onboard Symptoms and Inspection Findings

During active voyages, the engineering crew observed that the compressor required 45 minutes to charge the starting air bottles up to 30 bar, compared to the baseline design specification of 15 minutes. This continuous operation drove operating temperatures up to 88°C, triggering local thermal alarms.

Physical teardown inspections of the unit revealed significant defects. The suction filter element was saturated with thick carbonaceous particulate matter and oily soot. Upon opening the cylinder head assembly, the first-stage suction and delivery valves exhibited severe carbon fouling, rough seating surfaces, and pitting wear. Inspection of the piston assembly showed that the piston ring gap had expanded to 1.85 mm, significantly exceeding the manufacturer's maximum wear tolerance of 0.60 mm, confirming blow-by symptoms

Figure 1. Maintenance

Qualitative data derived from technical interviews corroborates the physical findings regarding the etiology of the compression failure.

On June 6, 2024, Chief Engineer Sjahnur emphasized that the reduction in pressure is primarily attributable to the structural failure of the compression seal; specifically, the inability of the suction and discharge valves to seat correctly due to carbon deposits leads to significant back-flow leakage. He further highlighted that the gradual increase in the piston ring gap allows compressed air to escape during the compression stroke, a progressive failure mode that frequently goes undetected until system efficiency drops critically (Sjahnur, personal communication, 2024).

Figure 2. Suction and Delivery Valve

The operational ramifications of these mechanical inefficiencies are substantial, posing risks to the vessel's maneuverability and safety. Second Engineer Imanuel noted that the failure to rapidly achieve the necessary pressure threshold for the starting air system results in critical delays during the activation of main and auxiliary propulsion units, thereby compromising the vessel's responsiveness during essential maneuvering or berthing operations (Imanuel, personal communication, 2024). To validate these contemporary observations, a retrospective review of maintenance journals from 2020 to 2022 was conducted, confirming a historical pattern of similar mechanical degradations affecting the vessel's operational readiness.

4.2 Before and After Maintenance Parameters

To confirm that corrective interventions successfully restored the auxiliary system's performance, precise measurable parameters were recorded before and after overhaul actions.

Table 1. Condition Before and After Repair

Before Repair	After Repair
Decreased temperature	Normal temperature
Noisy compressor	Normal compressor
Frozen evaporator	Normal evaporator
Clogged condenser	Normal condenser

4.3 Fault Tree Analysis

As illustrated in the structural mapping of the Fault Tree Analysis in Figure 3, the causal pathways are logically evaluated:

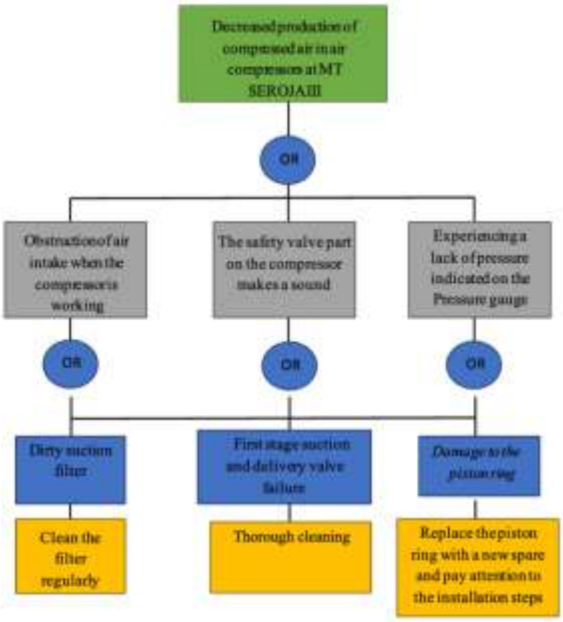

Figure 3. Fault Tree Analysis

Note: The functional logic of Figure 3 traces how the top event is driven by individual basic failures. Filter occlusion blocks intake air; carbon deposits on first-stage valves trigger backflow pressure waves that cause safety valves to sound; and worn piston rings lead to low discharge gauge readings due to intra-cylinder pressure loss.

4.4 Corrective Maintenance Subsection

To resolve the identified root causes, the engine department executed targeted corrective maintenance procedures:

Filtration Restoration: The filter housing was dismantled, and the saturated element underwent reverse-flow pneumatic purging. The internal housing was chemically flushed with specialized solvent to eliminate oleaginous residues.

Valve Overhaul: The first-stage valve assemblies were completely disassembled. Carbon deposits and heavy sludge were chemically dissolved, followed by precision mechanical refacing and lapping to restore the airtight sealing surfaces. Gaskets and valve plates were replaced with original manufacturer spares.

Piston Ring Replacement: The cylinder head was unbolted, and the piston assembly was extracted safely using a chain block to preserve cylinder liner integrity. After cleaning the carbonized ring grooves, new piston rings were installed with ring gaps carefully staggered at 120-degree intervals to eliminate blow-by pathways. Reassembly was tightened in a cross-torque pattern according to the manual instructions, followed by a controlled break-in running period.

4.5 Theoretical Analysis and Comparison

Linking these findings to fluid mechanics and compressor performance theory clarifies the degradation process. Saturated filtration restricts mass airflow, forcing the compressor to work under high intake vacuum conditions, which cuts volumetric capacity. Valve leakage causes hot compressed air to slip back into the suction chamber during the compression stroke, causing continuous re-compression that spikes operating temperatures and delays air receiver accumulation. Worn piston rings allow high-pressure air to escape down into the crankcase (blow-by), causing irreversible compression loss.

These results align with findings by Chabiba (2021) and Perdana et al. (2022), who concluded that carbon fouling and ring wear are the dominant physical nodes causing compressor output drops on merchant ships. This study demonstrates that reactive repairs can be minimized through condition monitoring. If the crew neglects the Planned Maintenance System (PMS), minor filter blockages cause a cascading thermal rise that breaks down oil stability, accelerates valve carbon deposits, and ultimately causes ring failure. Maintaining auxiliary compressor reliability is critical for shipboard safety; sudden compression failure directly halts main engine starting capability, eliminating emergency response and vessel maneuverability during critical port navigation.

reliability.

5 Conclusion

The investigation into the compromised pneumatic efficiency onboard MT Seroja III confirms that the decrease in compressed air production was driven by three primary technical failure nodes: particulate fouling of the suction filtration system, severe carbonaceous accumulation on the first-stage suction and delivery valves, and mechanical wear of the piston rings beyond acceptable tolerance limits. These interconnected deficiencies caused severe blow-by, restricted volumetric efficiency, and forced continuous overheating cycles.

Corrective maintenance actions—including high-pressure pneumatic filter purging, precision valve refacing, and the installation of specification piston rings with staggered clearances—effectively resolved the pressure drop. Post-repair parameter tracking demonstrated full performance restoration, reducing the air receiver filling time from 45 back to 15 minutes and stabilizing operating temperatures at 68°C.

To ensure long-term operational reliability and prevent cascading auxiliary failures, it is recommended that the ship's technical management enforce strict compliance with the Planned Maintenance System (PMS). Marine engineers must implement regular, condition-based inspections, including weekly suction filter cleaning, periodic valve deposit solvent flushes, and precise tracking of lubrication oil parameters to prevent oil carryover and carbon buildup.

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