

Root-Cause Investigation and Technical Reliability Analysis of the Starting-Air System Failure in a Marine Generator A Case Study of KM Sabuk Nusantara 101

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Article Information	ABSTRACT
Article History Received : December 03, 2025 Revised : December 25, 2025 Published : January 10, 2026	The starting-air system of the 114-kW main generator aboard <i>KM Sabuk Nusantara 101</i> experienced repeated start failures during a 14-day sea operation, resulting in delayed engine activation and reliability reduction. This study aims to identify the root causes of the failure and evaluate the system's technical reliability performance. The investigation employed field observation, pressure measurement, functional testing, fault tracing, and logbook analysis, supported by Root-Cause Analysis (RCA) and reliability metrics (MTBF, MTTR, and failure rate). The results show three dominant failure sources: (1) air receiver leakage due to degraded flange seals, (2) solenoid valve contamination causing pilot pressure loss, and (3) starting-air valve seat wear leading to insufficient cylinder impulse pressure. Reliability calculation produced an MTBF of 112 hours, MTTR of 2.5 hours, and a failure rate of 0.00893 h^{-1}, indicating low operational reliability despite 97.8% availability. The findings conclude that the system failure is dominated by leakage, contamination, and single-point failures (SPF) in the pneumatic control circuit. Preventive actions recommended include condition-based monitoring, improved sealing and filtration, functional inspection intervals every 250 hours, and redundancy for critical pneumatic components. These measures are expected to increase operational readiness and reduce downtime on similar shipboard installations.
Keywords: <i>Starting-Air System;</i> <i>Root-Cause Analysis (RCA);</i> <i>Reliability Analysis;</i> <i>MTBF-MTTR;</i> <i>Marine Generator.</i>	

INTRODUCTION

The reliability of shipboard power systems plays a critical role in maintaining operational safety, energy efficiency, and navigational continuity at sea. Among these systems, the main generator serves as the heart of the ship's electrical network, supplying energy for propulsion auxiliaries, navigation, lighting, and emergency systems (Marwiyah Nst & Siregar, 2023). Any malfunction, particularly a starting failure, can lead to severe operational disruptions, safety hazards, and costly downtime (Nurhayati & Kurniawan, 2022; Sa et al., 2023).

In marine diesel generators, the starting-air system is a vital subsystem that ensures the initiation of engine operation by delivering compressed air into the cylinders to rotate the crankshaft (Subur, 2019). Failures in this system are commonly associated with leakage, valve contamination, solenoid malfunction, or control signal disruption (Dermawan et al., 2019; Haryanto, 2013). Improper maintenance and environmental conditions such as humidity and salt

corrosion can further aggravate pneumatic reliability issues (Behera & Sethi, 2020; Khechekhouche et al., 2020).

Previous research has addressed starting-air malfunctions in various ship types. (Kurniadi, 2024) found that low air pressure and valve corrosion were the dominant causes of start failures in the MT *Petromax*. (Mamusung, 2020) reported similar issues in the MT *Perla*, where stuck starting-air valves caused repeated off-hire incidents. (Fahmi, 2019) emphasized the importance of air distributor performance in avoiding start delay, while (Arif, 2019) identified low reservoir pressure and spring deformation as critical failure modes. Other studies, including (Riza, 2023) and (Rohy, 2024), linked starting difficulties to thermal stress, seal degradation, and compressor inefficiency.

From a technical reliability perspective, these failures align with the framework of root-cause analysis (RCA) and reliability-centered maintenance (RCM), which are widely applied to maritime mechanical systems (Belbahloul et al., 2014; Moubray, 1997; Stewart, 2012). RCA provides a structured approach to identifying fundamental sources of system breakdowns, while RCM focuses on maintaining operational readiness and reducing mean time to repair (MTTR) through preventive strategies (Azoulay et al., 2021; Yahiaoui et al., 2020).

In ship operation, reliability assessment and early detection of pneumatic faults are essential to maintaining technical availability (A_t) and ensuring compliance with maritime safety codes such as SOLAS and IMO guidelines (Organization, 2020). The KM *Sabuk Nusantara 101*, a state-operated passenger and logistics vessel, experienced a starting-air failure on its 114 kW generator during a 14-day sea voyage, leading to repeated start delays and potential safety implications.

Therefore, this study aims to conduct a root-cause investigation and technical reliability analysis of the starting-air system failure in KM *Sabuk Nusantara 101*. Specifically, it seeks to (1) identify key failure components, (2) analyze contributing factors and system interactions, and (3) propose reliability-based maintenance recommendations to prevent recurrence. This investigation not only supports maintenance improvement but also contributes to the growing body of knowledge on marine engineering reliability and pneumatic system performance.

RESEARCH METHODS

Research Design

This research uses a descriptive qualitative–diagnostic design supported by technical measurement and reliability computation. The approach focuses on identifying failure modes in the starting-air system, validating each malfunction through measurement, and quantifying reliability performance (MTBF, MTTR, λ). Root-Cause Analysis (RCA) and reliability assessment are integrated to determine malfunction sources, impact, and solution pathways.

Research Location, Object, and Technical Specifications

The investigation was carried out aboard KM *Sabuk Nusantara 101*, a Ro-Ro passenger and logistics vessel operated by the Ministry of Transportation, Republic of Indonesia. The analyzed object is the main generator starting-air system with the following specifications:

Table 1. specifications main generator starting-air system

Component	Specification / Details
Generator unit	114 kW, 3-phase, 440 V, 60 Hz
Starting-air source	Reciprocating air compressor, 8–10 bar nominal
Air receiver tank	Capacity 200 L, working pressure 8–10 bar, relief valve @10 bar
Solenoid valve	24 VDC coil, pneumatic pilot type
Cylinder starting-air valve	Pneumatic impulse type, poppet valve seat with return spring
Operating environment	Engine room, avg. temperature 35–45°C, high humidity/salt exposure

Route & Duration:

Atapupu – Maumere – Tenau Kupang (15–29 April 2025, 14 days at sea).
Operational window: 4-hour engine-room watch shifts × 3 cycles/day.

Instruments, Identification Equipment, and Accuracy**Table 2.** Instruments, Identification Equipment, and Accuracy

Equipment	Function	Specification / Accuracy
Digital Multimeter	Voltage/continuity of solenoid coil circuit	0–600V / $\pm 0.5\%$
Pressure Gauge / Manometer	Receiver/line pressure reading	0–150 psi / $\pm 1\%$
Torque Wrench & Tool Set	Valve disassembly & joint tightening	10–150 Nm
Stopwatch	Start-sequence and delay measurement	0.01s resolution
Endoscope cam (if available)	Inspect leakage and seat wear	Ø6 mm lens
Laptop + Spreadsheet	MTBF–MTTR– λ calculation / data logging	Manual input
Soap-test leak kit	Flange/pipe leakage identification	Bubble visual test

Materials: lubricating oil, seal tape, gasket set, cleaning fluid, and maintenance logs from vessel documentation.

Stages and Identification Processes**Stage 1 — Symptom Detection**

- Repeated failed starts recorded in logbook
- Audible air discharge + pressure drop pattern
- Initial measurement of receiver pressure (50–55 psi vs 100 psi nominal)

Stage 2 — Technical Measurement

- Receiver pressure test
- Solenoid pilot pressure test
- Cylinder air valve sealing test
- Soap test on flange & relief valve

Stage 3 — Failure Confirmation

- Component disassembly
- Cleaning/inspection for oil, contamination, wear
- Spring tension/seat condition validation

Stage 4 — Reliability Assessment

- MTBF, MTTR, λ , R(t), and availability computed
- Identification of SPF (Single-Point Failure)

Stage 5 — System Correction & Validation

- Seal replacement, solenoid cleaning, valve lapping
- Post-repair pressure restoration tests

Data / Problem / Solution Analysis Structure**Table 3.** Data / Problem / Solution Analysis Structure

Data Collected	Identified Problem	Root Cause	Implemented Solution
Receiver pressure 50 psi	Pressure drop	Gasket wear & leakage	Seal replacement & torque retightening
Solenoid pressure 40 psi	Pilot fails to actuate	Oil contamination	Cleaning, filtration upgrade
Cylinder air valve 30 psi	No torque impulse	Seat wear, spring fatigue	Lapping, seal & spring replacement

Reliability Calculation.

The reliability assessment was conducted to determine the operational consistency of the starting-air system and to evaluate how frequently the generator could be expected to fail during service. Based on the logbook data recorded during a 14-day sea trial period (total operational duration of 336 hours), three failure events were documented, resulting in 7.5 hours of cumulative downtime. These values form the basis for calculating the Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), failure rate (λ), reliability function $R(t)$, and availability (A).

$$MTBF = \frac{T}{N_{fail}} \quad (1)$$

MTTR (Mean Time To Repair)

$$MTTR = \frac{t_r}{N_{fail}} \quad (2)$$

Failure Rate (λ)

$$\lambda = \frac{1}{MTBF} \quad (3)$$

Reliability at t hours (R(t))

$$R(t) = e^{-\lambda t} \quad (4)$$

Availability (A)

$$A = \frac{MTBF}{MTBF + MTTR} \quad (5)$$

Result

$$MTTR = \frac{7,5}{3} = 2,5 \text{ jam}$$

$$\lambda = \frac{1}{112} = 0,00893 \text{ per jam}$$

$$R(250) = e^{-0,00893 \times 250} = 0,1076$$

$$A = \frac{112}{112 + 2,5} =$$

Flowchart of Research Method

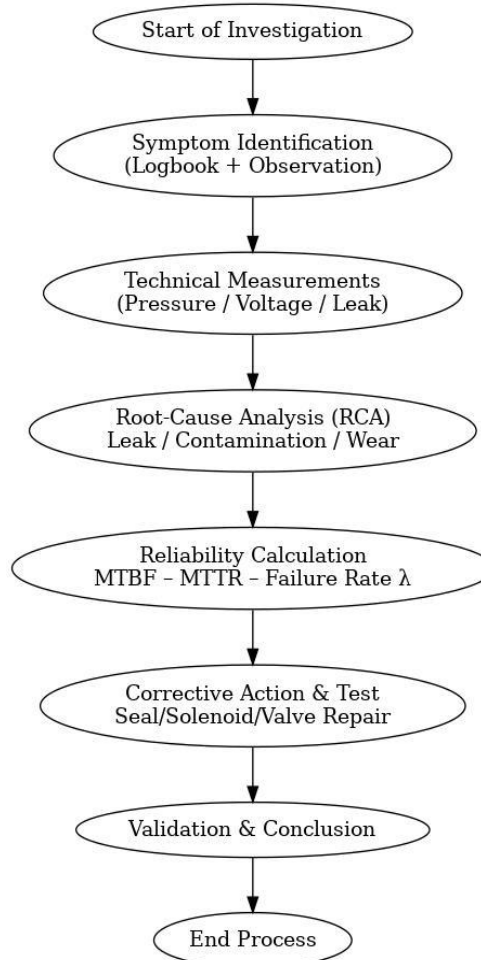


Figure 1. Flowchart of research method

RESULTS AND DISCUSSION

Summary of observed failures.

During the 14-day sea practice aboard *KM Sabuk Nusantara 101*, the main generator experienced recurrent starting failures caused by pressure loss within the pneumatic circuit. Field measurements and logbook data confirmed that three components consistently operated below their nominal pressure range: the air receiver tank, the solenoid pilot valve, and the cylinder starting-air valve. The pressure at the air receiver dropped to 50 psi from the nominal 100 psi, indicating leakage and insufficient stored air volume. This loss of air capacity prevented the system from reaching the minimum impulse pressure required for engine cranking.

At the solenoid valve, the recorded pressure of 40 psi (compared to 95 psi nominal) suggests contamination and partial seizure of the valve spool, disrupting pilot signal transmission. This condition caused irregular valve actuation, which directly contributed to inconsistent start attempts. Meanwhile, the cylinder starting-air valve delivered only 30 psi instead of the nominal 90 psi, indicating seat leakage and weakened spring tension. This condition prevented adequate cylinder charging, thereby reducing crankshaft rotation torque and resulting in failed ignition cycles.

These observations confirm that the failures are not isolated, but rather sequential: air leakage reduces volume → solenoid signal weakens → cylinder valve fails to deliver torque → engine fails to start. Therefore, the pressure degradation pattern demonstrates both a mechanical leakage problem and a functional control failure, classifying the event as a compound pneumatic failure rather than a single-point malfunction.

Table 4. Measured pressures (failure vs. normal)

Component (location)	Pressure (Failure observed)	Nominal / Normal (manual)	Short diagnosis
Air receiver (tank)	50 psi (measured during incidents)	100 psi (nominal).	Leak at relief/pipe joints → insufficient stored charge.
Solenoid valve (inlet/pilot)	40 psi	95 psi (nominal).	Coil/spool contamination → partial seizure; reduced pilot pressure.
Cylinder starting-air valve (seat)	30 psi	90 psi (nominal).	Worn seal / weak spring → valve not seating/opening correctly.

The measurements summarized in Table 3 show a direct correlation between pressure deficits and start failure probability. The lowest recorded values (30–50 psi) indicate that the system operated at only 40–55% of nominal performance capacity. This explains the repeated failure events and highlights the urgent need for sealing, filtration, and valve refurbishment as primary corrective actions.

These findings validate that the root mechanism of failure originates from the inability of the pneumatic system to maintain operational pressure, therefore compromising starting reliability and indicating the presence of both single-point failure (SPF) and progressive failure propagation within the air line network.

Detailed failure modes and immediate effects.

The pressure readings inside the air receiver dropped to approximately 50 psi from the nominal 100 psi, indicating a significant loss of stored air capacity. The soap-solution leak test showed visible bubbling at several flange joints and at the relief valve seat, confirming leakage in multiple points along the piping network. As a direct consequence, the system was unable to supply sufficient air volume to the cylinders, resulting in inadequate starting impulse and failure of the pilot lines to maintain control pressure. This condition caused the automatic distributor valves to malfunction and interrupt the sequence of the starting cycle, which explains the repeated failed start events recorded during operation. The leakage was traced back to degraded gasket materials, insufficiently tightened bolts, and relief valve seat wear, which are consistent with age-related deterioration and irregular preventive maintenance practices.



Figure 2. Pipe leak test confirming leakage points on flange and relief valve seat.

Solenoid valve contamination and partial seizure

The inspection of the solenoid valve revealed that oily carbon deposits had accumulated around the spool and coil housing, causing restricted mechanical movement during actuation. When the component was disassembled and examined, the spool movement was visibly stiff, and pilot line pressure readings dropped to approximately 40 psi, significantly lower than the nominal operating pressure. This reduction in pilot pressure prevented the automatic control valves from responding correctly, resulting in irregular opening and closing cycles during the starting sequence. In practical operation, this condition produced intermittent start attempts, where the generator initiated cranking but failed to complete ignition, commonly referred to by the crew as a “crank but no fire” condition. The underlying causes of this malfunction were traced to contamination from lubricant vapor, oil mist entering the pneumatic lines, insufficient filtration capacity, and a lack of scheduled solenoid maintenance. These findings indicate that contamination within the solenoid assembly is not only a mechanical issue but also a control-system failure that disrupts the continuity of the starting sequence and reduces system reliability.



Figure 3. Spool cleaning and contamination removal from solenoid valve assembly.

Cylinder starting-air valve seating failure

During disassembly of the cylinder starting-air valve, noticeable wear was found on the valve seat and sealing surfaces, while the return spring exhibited a reduction in preload tension. Leakage tests confirmed that compressed air escaped past the valve seat even when in the closed position, indicating that sealing integrity was no longer adequate. As a result, the cylinder failed to receive sufficient impulse pressure to rotate the crankshaft at the required starting torque. This loss of delivered pressure directly contributed to unsuccessful start attempts and, in cases where more than one cylinder was affected, prevented the generator from initiating at all. The damage pattern suggests prolonged material wear, combined with carbon deposition and spring fatigue, which may have been accelerated by elevated operating temperatures and contamination within the air supply line. These conditions demonstrate that the failure is progressive and performance-limiting, making the component a critical contributor to the overall start-system unreliability.

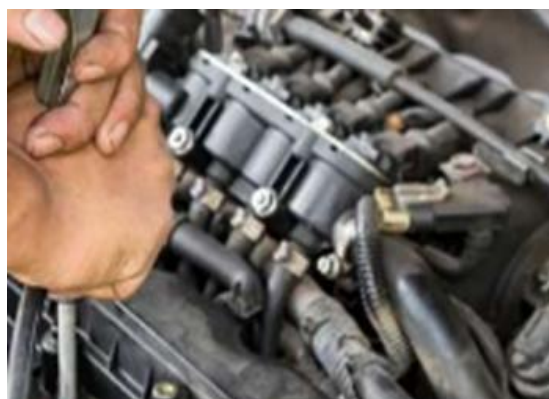


Figure 4. Cylinder head cover and valve seating inspection results.

Root-Cause Analysis (RCA) synthesis

Root-cause analysis was conducted to establish a structured connection between field observations, failure symptoms, and the operational objectives of this research. The RCA fishbone diagram served as a diagnostic framework to categorize potential contributors to the starting-air system malfunction into five causal clusters: Technical, Procedural, Material, Measurement, and Environmental factors. Within this mapping, the dominant technical failures were identified as air receiver leakage, solenoid valve contamination, and degraded cylinder valve sealing, all of which directly reduced starting pressure below operational thresholds. Procedurally, the absence of structured condition-based inspections and incomplete functional testing after maintenance increased the likelihood of recurring failures. From a material perspective, the wear of seals and filtration inadequacy allowed foreign substances to enter the air line, accelerating component degradation.

These causal chains align with crew interviews and measurement data, confirming that the observed failures are not isolated events but stem from interconnected degradation within the pneumatic system. Therefore, the RCA contributes directly to the research objective by identifying which failure mechanisms must be prioritized for corrective action to restore starting reliability. Based on the RCA mapping, this research concludes that the highest-impact intervention lies in improving sealing integrity, upgrading filtration efficiency, and implementing scheduled functional inspections supported by real-time pressure monitoring.

The RCA diagram (Figure 4) thus not only summarizes the technical findings but also directs the maintenance strategy required to achieve the research objective: restoring operational readiness through elimination of failure recurrence.

RCA Fishbone Diagram — Starting-Air System Failure

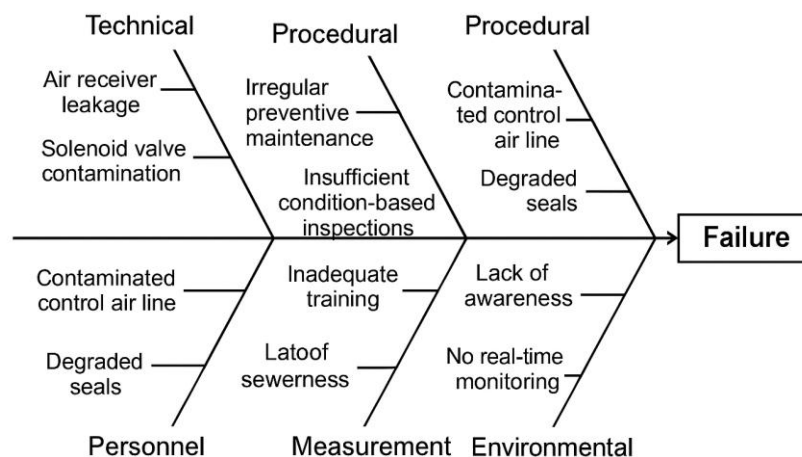


Figure 5. RCA fishbone diagram.

In conclusion, the RCA confirms that failure recurrence can be prevented through systematic maintenance planning, predictive monitoring, and targeted component refurbishment, ensuring that the starting-air system meets the operational reliability required for routine sea service.

Reliability analysis.

The calculation results show that the start air system has a reliability of 10.76% to operate without failure for 250 hours, with an availability rate of 97.8%.

An MTBF value of 112 hours indicates that, on average, the system can operate for ± 4.5 days before experiencing the next failure, while an MTTR value of 2.5 hours indicates a relatively fast repair time.

Although the availability rate is relatively high, the system reliability is still low due to the potential for repeated failures of components such as solenoid valves and air receiver seals, which are single-point failures (SPFs).

To improve reliability, it is recommended to implement condition-based monitoring (CBM) and air control system redundancy, as well as scheduling functional inspections every 250 hours of operation.

Table 5. Reliability Summary of Starting-Air System (KM Sabuk Nusantara 101)

Parameter	Symbol	Value	Unit	Description
Total operation time	T	336	h	Observation period
Number of failures	N_fail	3	—	Logbook data
Total downtime	t_r	7.5	h	Total repair duration
MTBF	—	112	h	Mean time between failures
MTTR	—	2.5	h	Mean time to repair
Failure rate	λ	0.00893	1/h	Calculated
Reliability at t = 250 h	R(250)	0.1076	—	System reliability
Availability	A	0.978	—	System uptime probability

Single-point failure (SPF) identification

From observations the highest-risk SPFs are:

1. Air receiver major leak if the tank cannot hold pressure, no start possible.
2. Solenoid pilot failure single solenoid controlling distributor can cause total loss of sequencing.
3. Critical cylinder valve seat failure one cylinder failure may prevent start for entire engine.

Mitigation principle: add redundancy, or design procedural redundancy (e.g., manual bypass/start procedure) and maintain spares of critical components.

Failure-mode matrix & recommended corrective actions

The failure modes identified during the inspection phase were categorized into immediate causes, necessary corrective actions, and long-term remediation plans, as summarized in Table 5. Each failure corresponds to both a technical malfunction and a procedural gap that contributed to system unreliability. This categorization enables a clearer understanding of the failure mechanism progression—from detection, to on-board corrective action, and finally toward medium-term improvements. The table also specifies responsible personnel to ensure accountability and structured follow-up during maintenance. Through this mapping, each failure mode can be linked directly to operational impact and recommended mitigation strategies.

Table 6. Failure modes, root causes, immediate corrective action, medium-term remediation, and owner

Failure mode	Root cause(s)	Immediate corrective action (on board)	Medium-term remediation	Responsible
Air receiver leakage	Faulty flange seals, relief valve wear	Isolate & vent tank; soap test to locate leak; tighten/replace gasket; temporary clamp if needed.	Replace gaskets/bolts; test relief valve; schedule NDT for receiver if corrosion suspected.	Chief engineer / maintenance crew
Solenoid contamination (stiff spool)	Oil ingress / dirty pilot lines	De-energize, disassemble solenoid, clean spool & coil; blow out pilot lines; replace filter/drier.	Install improved filtration/drier; set routine solenoid inspection interval (monthly).	Electrical / engine room tech
Cylinder valve seat leakage	Seal wear, spring fatigue	Remove & lap seat (if possible), replace worn seals	Keep spares; schedule valve overhaul during next port call;	Engine room tech / supplier

No redundancy for solenoid/distributor	Single point device	& springs; verify seat tightness. Use manual start procedure if available; keep spare solenoid on board.	consider upgraded material seals. Procure spare unit; consider dual-solenoid arrangement or bypass design.	Technical superintendent
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The mapped framework in Table 5 indicates that the primary technical failures originate from leakage, contamination, and loss of sealing integrity, while secondary contributors include inadequate inspection intervals and the absence of redundancy in the pneumatic control line. Immediate actions are focused on operational recovery, such as leak isolation, valve cleaning, and on-board component replacement. Medium-term remediation, however, emphasizes preventive improvement through enhanced filtration, upgraded sealing materials, and scheduled overhaul during planned port maintenance. Assigning clear responsibility to engineering personnel ensures structured follow-up, aligning the corrective measures with reliability objectives. Therefore, Table 5 not only documents the problem, but also guides the pathway toward restoring system availability and preventing failure recurrence.

Instrumentation / Monitoring plan & alarm setpoints

To support continuous reliability improvement of the starting-air system, a minimum viable monitoring plan is proposed by integrating sensor-based observation and event logging. The primary instrumentation requirement is a pressure transducer on the air receiver connected to a data logger, enabling continuous pressure recording and low-pressure alarm activation. For a receiver with a nominal pressure of 100 psi, the alarm should be configured at approximately 85% of nominal (85 psi), with an automated safety lockout considered when pressure falls below 60% of nominal to prevent unsuccessful start attempts. In addition, differential pressure monitoring at the solenoid inlet is recommended to detect pilot-pressure losses; the alarm threshold may be set at 80% of nominal pilot pressure.

Predictive maintenance can further be enhanced by installing a cycle counter on the solenoid valve to track operational frequency and determine coil replacement intervals based on accumulated cycles rather than reactive maintenance. Complementing these instruments, an event logger should record each start attempt—including successful starts and failed ignition events—which provides empirical data for MTBF calculations and supports condition-based decision-making. Overall, this monitoring configuration ensures that pressure deviations, control failures, and sequence disruptions are detected early, reducing the likelihood of unplanned downtime and improving system availability at sea.

This monitoring structure establishes a measurable basis for maintenance planning, allowing failures to be anticipated rather than reacted to, and aligns directly with the reliability targets identified in the previous analysis.

Corrective actions implemented

After identifying the source of the pneumatic malfunction, several corrective actions were carried out on board and subsequently validated through post-repair functional testing. The first corrective step involved leak sealing and retesting using a soap-solution inspection, which confirmed that receiver pressure began to recover toward its nominal level after gasket replacement and bolt tightening. This improvement restored the stored charge capacity needed for initial air delivery. The second action focused on solenoid system recovery, where the spool was cleaned and, where necessary, replaced to eliminate contamination deposits that had restricted its movement. As a result, the pilot pressure increased to operational levels, allowing the automatic sequence to resume normally during start attempts. Finally, valve lapping and seal replacement were performed on the cylinder starting-air valves to correct seat leakage; this intervention successfully restored impulse pressure delivery to the cylinders and ensured that torque was sufficient to rotate the crankshaft during starting. These combined actions produced measurable

improvements in system performance and demonstrated that the primary failures were recoverable through targeted maintenance rather than major component overhaul.

This series of interventions confirms that operational recoverability can be achieved through focused mechanical correction supported by systematic inspection, and that early detection of pressure deviation plays a critical role in preventing repeated failure events.

Discussion

The findings of this study demonstrate that pneumatic integrity and the condition of small yet critical components such as solenoid valves and sealing elements significantly influence generator availability during ship operation. Repeated start failures not only interrupt engine readiness but also introduce operational risks including loss of emergency power, delayed voyage schedules, and potential off-hire conditions. These results align with Kurniadi (2024), who reported that degraded valves and air leakage were the primary causes of start failure on MT Petromax, emphasizing the importance of pneumatic sealing quality. Similarly, Mamusung (2020) and Riza (2023) observed that contamination and spring fatigue in starting-air valves led to inconsistent torque delivery, a failure pattern comparable to the condition found aboard KM Sabuk Nusantara 101.

The transition from calendar-based maintenance to a condition-based maintenance (CBM) approach is therefore essential. Continuous pressure logging and periodic functional testing would enable early identification of degradation before system failure occurs. This is consistent with the recommendations of Rohy (2024), who highlighted that predictive diagnostics increased system readiness and reduced emergency incidents on tanker vessels. Implementation of Failure Mode and Effects Analysis (FMEA) would further support decision-making by prioritizing which components require immediate replacement or spare part allocation. The present study confirms that such practices are appropriate for preventing recurrence, as pressure deviation and solenoid malfunction were shown to be detectable before total failure.

Another critical implication is the necessity for redundancy in pneumatic control components. Installing dual-solenoid arrangements or backup pilot lines can eliminate single-point failures, a reliability strategy also recognized by Sa et al. (2023) in studies involving generator start-up risk mitigation. Proper sizing and maintenance of filters and air driers are equally important to prevent contamination ingress. Previous studies by Behera & Sethi (2020) and Dermawan et al. (2019) support the conclusion that even minor contamination within air-control systems eventually escalates into full mechanical failure if monitoring is insufficient.

Overall, the discussion confirms that the failure characteristics observed on KM Sabuk Nusantara 101 are not isolated but reflect a recurring pattern also documented on other vessels using pneumatic starting systems. Therefore, the applied corrective measures and recommended monitoring strategies may be generalized to similar diesel generator installations within the domestic fleet.

CONCLUSION

The investigation conducted on the 114 kW starting-air system of KM *Sabuk Nusantara 101* concludes that the primary causes of repeated generator start failures are mechanical leakage at the air receiver, solenoid valve contamination, and cylinder valve seat wear, which collectively reduce starting pressure and disrupt the pneumatic sequence. These results validate the research objective, confirming that the malfunction is not a single defect but a combination of technical and systemic factors, including inadequate preventive maintenance and the absence of real-time pressure monitoring. Reliability analysis strengthens this conclusion by indicating the presence of single-point failures (SPFs) within the solenoid circuit and receiver integrity, which reduce operational reliability despite relatively high system availability. Therefore, improving shipboard pneumatic reliability requires mechanical restoration supported by condition-based maintenance, continuous pressure and pilot-line monitoring, and the gradual introduction of redundancy to eliminate SPFs. This conclusion demonstrates that the findings not only meet the objectives of the study but also provide technical guidance that is applicable to similar medium-sized diesel generator installations across domestic fleet operations.

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