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ENHANCED PREVENTIVE MAINTENANCE STRATEGY TO OPTIMIZE MAIN ENGINE STARTER SYSTEM PERFORMANCE ON MARINE VESSELS

Strategi Perawatan Preventif untuk Mengoptimalkan Kinerja Sistem Starter Mesin Utama pada Kapal

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ABSTRACT

The starter system is a vital component in the main engine starting process on a ship, so its reliability is an important factor in ensuring smooth sailing operations. This study aims to analyze the effectiveness of implementing preventive maintenance in improving the performance of the main engine starter system on a passenger ship. The study was conducted on the XYZ ship using a descriptive method through direct observation and interviews with the engineer officer. Data obtained included the physical condition of the battery, cable path, solenoid, and internal components of the starter dynamo, then analyzed based on performance parameters before and after preventive maintenance. The results showed several major problems, including heavy starter rotation, rapid battery voltage drop, loose cable connections, and damage to the solenoid. After implementing preventive maintenance such as adding battery water, cleaning terminals, tightening cable connections, and internal maintenance of the starter, there was a significant increase in engine starting speed, battery voltage stability, and starter response. The frequency of previously frequent problems also decreased drastically. The conclusion of this study is that preventive maintenance is proven to be effective in improving starter system performance, reducing the risk of starting failure, and supporting the smooth and safe operation of the ship as a whole. Implementation of scheduled preventive maintenance is recommended to ensure long-term reliability of the starter system.

Keywords: Machinery Reliability, Ship Electrical, Maintenance Management, Damage Analysis, Navigation Safety.

ABSTRAK

Sistem starter merupakan komponen vital dalam proses penghidupan mesin induk pada kapal, sehingga keandalannya menjadi faktor penting dalam menjamin kelancaran operasi pelayaran. Penelitian ini bertujuan untuk menganalisis efektivitas penerapan pemeliharaan preventif dalam meningkatkan performa sistem starter mesin induk pada kapal penumpang. Penelitian dilakukan pada kapal XYZ dengan menggunakan metode deskriptif melalui observasi langsung dan wawancara terhadap perwira mesin. Data yang diperoleh mencakup kondisi fisik baterai, jalur kabel, solenoid, serta komponen internal dinamo starter, kemudian dianalisis berdasarkan parameter performa sebelum dan sesudah pemeliharaan preventif. Hasil penelitian menunjukkan adanya beberapa gangguan utama, antara lain starter berputar berat, baterai cepat mengalami penurunan tegangan, koneksi kabel longgar, serta kerusakan pada solenoid. Setelah penerapan pemeliharaan preventif seperti penambahan air aki, pembersihan terminal, pengencangan sambungan kabel, dan perawatan internal starter, terjadi peningkatan signifikan pada kecepatan penghidupan mesin, stabilitas tegangan baterai, dan respons starter. Frekuensi gangguan yang sebelumnya sering muncul juga menurun secara drastis. Kesimpulan dari penelitian ini adalah bahwa pemeliharaan preventif terbukti efektif dalam meningkatkan performa sistem starter, mengurangi risiko kegagalan start, serta mendukung kelancaran dan keselamatan operasional kapal secara keseluruhan. Implementasi pemeliharaan preventif yang terjadwal direkomendasikan untuk memastikan keandalan sistem starter dalam jangka panjang.

Kata Kunci: Keandalan Permesinan, Kelistrikan Kapal, Manajemen Pemeliharaan, Analisis Kerusakan, Keselamatan Pelayaran.

INTRODUCTION

Indonesia is an archipelagic country with vast maritime territory spread across thousands of islands (Nugraha, 2020). This geographical location makes maritime transportation a vital mode of transportation, supporting community mobility, logistics distribution, and interregional economic activity (Amin *et al*., 2024; Apriliani *et al*., 2020; Panjaitan *et al*., 2025; Pramoda *et al*., 2021; Sibali & Jainuddin, 2024; Suryanto & Wudianto, 2017). To perform these functions safely and efficiently, operating vessels must have optimally and reliably operating machinery systems at all times.

One of the most critical components in a ship's operation is the main engine, as it serves as the primary propulsion system, turning the propellers, enabling the ship to move (Marsudi & Palippui, 2020; Nugraha & Malelak, 2024; Pakaya *et al*., 2023; Priharanto *et al*., 2023). The main engine cannot operate independently without the support of several other supporting systems, such as the fuel system, cooling system, lubrication system, and starter system (Djeli & Saidah, 2016; Yaqin *et al*., 2020; Ziliwu, 2022; Ziliwu *et al*., 2021). Among these systems, the starter system plays a crucial role as it initiates the entire engine operation (Nugraha *et al*., 2025). Without a properly functioning starter system, the main engine cannot be started, and all ship operations will come to a halt (A *et al*., 2024; Nur Rahman *et al*., 2025).

In practice, starter system problems are quite common. Some common problems include battery failure, deterioration of cable connections, terminal corrosion, solenoid damage, and decreased starter dynamo performance (Fathyunes & Mohtadi-Bonab, 2023; Nur Rahman *et al*., 2025). These disturbances can cause the main engine to be difficult to start, take longer to start, increase electricity consumption, and even lead to total engine failure during the start-up process. This situation is certainly very detrimental, especially for vessels operating routinely and with tight sailing schedules.

One of the main causes of starter system disturbances is the suboptimal implementation of preventive maintenance. Many routine maintenance tasks, such as battery condition inspections, voltage measurements, terminal cleaning, cable connection tightness checks, and starter dynamo component inspections, are not carried out according to procedure. Without scheduled maintenance, components wear out undetected, increasing the risk of sudden failure (Nur Rahman *et al*., 2025; Prayogo & Gelesah, 2018).

Implementing preventive maintenance is a crucial step to ensure the starter system is always in good working order (Lim *et al*., 2025). With proper maintenance, potential disturbances can be detected early, component lifespan is extended, and system reliability is increased. Furthermore, consistent preventive maintenance helps prevent engine downtime, minimizes the risk of operational delays, and reduces the typically higher costs of emergency repairs (Egas & Kusuma, 2025; Mursidi & Sarjito, 2025).

Considering the importance of the starter system in supporting the readiness of the main engine and the significant impact it can have if a fault occurs, a study is needed to describe how preventive maintenance is implemented and to what extent it can improve the performance of the starter system. This study aims to analyze the condition of the starter system, identify components that require special attention, and evaluate the effectiveness of preventive maintenance in improving its performance. The results of this study are expected to serve as a reference in implementing more structured and sustainable routine maintenance so that the operation of the main engine can be more reliable, efficient, and safe.

METHODS

This research was conducted from November 15, 2022 to January 15, 2023, on a passenger ship XYZ which operates regularly on daily shipping routes in East Nusa Tenggara (Figure 1). The ship operates from morning to evening and returns to anchor at night for operational preparation. The relatively stable operational conditions allowed for systematic data collection at various stages of the main engine startup. The research focused on the main engine starter system, specifically regarding the implementation of preventive maintenance and its impact on improving system performance.

Figure 1. XYZ Ship Serving Shipping in East Nusa Tenggara

The approach used in this research was a descriptive method. This method was chosen to provide a factual picture of the actual condition of the starter system, the implementation of preventive maintenance, and the symptoms of problems that occur during main engine operation. The descriptive method allows researchers to identify, record, and explain field findings in depth, thus providing relevant information for starter system optimization efforts.

Research data was obtained through two main techniques: direct observation and interviews. Observations were conducted by carefully observing the main engine startup process, the physical condition of the starter components, and technical parameters related to system performance. Observations were conducted using checklists and engine logbooks, which recorded battery voltage, starting time, cable terminal condition, component cleanliness, and previous maintenance history. Additionally, observations included inspections of components such as the battery, cables, terminals, solenoids, and starter motors to detect wear, corrosion, or loose connections that could potentially hinder the starting process.

Interviews were conducted to supplement the observation data by gathering information directly from engine personnel involved in the operation and maintenance of the starter system. The interviews were unstructured to allow respondents the flexibility to describe their field experiences, their maintenance practices, and the challenges or problems they frequently encounter when using the starter system. Information obtained from these interviews was used to understand how preventive maintenance is carried out, the limitations faced by crew members, and the effectiveness of existing maintenance practices.

The research instruments used included inspection checklists, engine logbooks, digital multimeters, hydrometers, and tools such as wire brushes and penetrant fluids. The multimeter was used to measure the voltage and current associated with the starter system, while the hydrometer was used to check the electrolyte density level in wet batteries. Meanwhile, wire brushes and penetrant fluid were used to assist in cleaning the battery terminals and other corroded components. All instruments were used consistently to ensure the technical data obtained was accurate and comparable throughout the research period.

Data analysis was conducted descriptively by categorizing field findings and then comparing them to the preventive maintenance standards that should be applied to the main engine starter system. This analysis included examining performance parameters such as battery voltage, voltage drop during starting, engine start-up time, starter dynamo rotation, and the frequency of faults. Furthermore, the physical condition of the components was analyzed to identify common problems such as rust on the terminals, loose cable connections, and damage to the starter dynamo or solenoid. The results of this analysis were used to determine the extent to which preventive maintenance improved starter system performance.

In the final stage, researchers evaluated changes in starter system performance after the implementation of preventive maintenance. This evaluation was conducted by comparing technical parameters before and after maintenance to determine the effectiveness of the maintenance measures. Changes in voltage values, decreased starting time, improved starter dynamo rotation, and reduced frequency of faults were the main indicators of improved starter system performance. The evaluation results are then summarized to provide more structured and sustainable preventive maintenance recommendations so that the main engine starter system can work optimally to support ship operations.

RESULTS

Ship Data

The XYZ ship is a fiberglass passenger ship used for sea transportation on the Kupang-Rote route. The use of fiberglass strengthens the ship's structure against corrosion and minimizes the risk of leaks. The ship has a gross tonnage of 254 GT and consists of several main compartments: the wheelhouse, cargo hold, engine room, and passenger compartments divided into several classes (VIP, A, B, C, and D). All passenger compartments are equipped with air conditioning and sanitation facilities. Additionally, a canteen is located at the stern of the ship.

The ship operates daily except during periods of inclement weather, government-mandated operational restrictions, or when the ship undergoes periodic dockings of approximately one month. The ship's specifications are shown in Table 1, while the ship's machinery data is presented in Table 2.

Table 1. Specifications of XYZ Ship

Description	Specification
Hull material	Fiberglass
Gross Tonnage (GT)	254 GT
Facilities	Air conditioning, restroom, canteen
Operational route	Kupang – Rote (round trip)
Operational frequency	Daily (except during bad weather or docking)

Table 2. Specifications of the Starter System Battery

Description	Specification
Brand / Type	Yuasa
Voltage	12 V
Capacity	200 Ah
Weight	25 kg
Battery type	Wet cell battery
Quantity	6 units (each main engine uses 2 batteries in series)

Identification of Starter System Faults

Based on direct observations in the engine room and interviews with ship officers and technicians, it was discovered that the main engine starter system was experiencing several faults that hampered the engine's starting process (Table 3). These faults not only made the engine difficult to start but also significantly increased battery energy consumption. The problems were recurring and indicated imperfections in the mechanical and electrical components supporting the starter motor's performance.

One of the main faults was difficulty starting the main engine, where the engine took longer than normal to reach initial revs. This symptom was evident when the starter button was pressed but initial revs were not immediately strong. This condition could be caused by an unstable initial fuel supply to the combustion chamber, suboptimal compression, or insufficient initial torque from the starter motor to rotate the crankshaft. In these conditions, the battery worked harder and longer to maintain starter revs, accelerating its voltage decline.

The next most common fault was the starter motor not turning at all or turning but feeling heavy. When the starter motor was unable to turn, the main engine was unable to reach the minimum speed required to initiate combustion. Meanwhile, the heavy starter rotation causes increased current draw, causing the battery to rapidly deplete. Component inspections revealed a weak battery, triggered by worn brush housings on the anchor shaft, resulting in excessive friction with the field coil. This friction creates rotational resistance and requires more current for the starter motor to operate, leading to faster battery drain.

Furthermore, loose or even broken positive and negative cable connections were found. This problem typically arises from continuous engine vibration during sailing operations, as well as the aging of the cables, which has led to their deterioration. Loose or peeling connections disrupt the flow of electrical current, preventing it from flowing stably to the starter motor. When current flow is inadequate, the starter motor does not receive optimal energy, resulting in heavy rotation or even complete failure.

Another problem identified was damage to the connecting solenoid. This component functions as an electromagnetic switch that connects the high current from the battery to the starter motor. Solenoid damage can occur when the cable connection previously produced a small spark, leading to blackening or a minor fire at the terminals. In addition, the solenoid can also become stuck or fail to return to its normal position due to mechanical wear and tear. When the solenoid fails, the starter motor will not receive the high current required to crank the engine, preventing normal starting.

Taken together, these problems indicate that the starter system is experiencing a combination of mechanical and electrical problems, as well as component wear from long-term use. Without scheduled preventive maintenance, these problems can recur and seriously impact the reliability of the main engine during the ship's operational life.

Table 3. Identification of Failures in the Main Engine Starter System

Type of Failure	Observed Symptoms	Primary Causes
Engine difficult to start	Engine requires longer time to start; unstable initial rotation	Unstable initial fuel supply; low initial compression; starter rotation insufficient
Starter motor does not rotate	Starter gives no response when the start button is pressed	Very weak battery; damaged solenoid; broken main cable
Starter motor rotates but is heavy	Starter rotates slowly; engine fails to reach minimum starting speed	Worn brush housing on armature shaft causing high friction; insufficient battery current
Battery drains quickly	Battery voltage drops drastically after several start attempts; battery becomes hot	Starter motor overload; friction on field coil; suboptimal charging system
Loose or broken cable connection	Starter works intermittently; small sparks on terminals; cable becomes hot	Engine vibration; aged cables; unsecured terminal fastening
Solenoid does not function	Starter motor receives no high current supply; audible “click” without rotation	Burnt solenoid terminal; damaged connection; solenoid sticking or minor burn

DISCUSSION

The Role of the Starter System in Main Engine Operation

The starter system is one of the most vital components in the main engine operation on a ship, particularly diesel engines, which require high initial torque to initiate combustion. A diesel engine cannot operate without reaching a minimum rotational speed that allows air to enter the combustion chamber, where it is compressed to initiate combustion. To achieve this initial rotational speed, the starter motor rotates the crankshaft at sufficient speed and torque for the engine to operate under its own power. Without optimal starter performance, the main engine cannot start, rendering the ship immobile.

The starter system consists of several main components: the battery, starter motor, solenoid, electrical cables, and supporting relays. The battery supplies a high current instantly, while the solenoid connects the current from the battery to the starter motor during the starting process. The starter motor then converts electrical energy into mechanical energy to rotate the main engine flywheel. The overall performance of the starter system is significantly affected by the condition of each of these components. Even minor damage such as dirty battery terminals, loose cables, or worn solenoids can cause the starting process to fail.

In the context of passenger ship operations, the reliability of the starter system is crucial. Ships operate daily, regularly scheduled voyages, requiring the main engine to be ready for smooth start-up. Even the slightest disruption to the starter system can cause departure delays, ultimately impacting service schedules, passenger comfort, and even the company's reputation.

Furthermore, repeated starting due to disruptions can drain battery power, increase the workload on the starter motor, and accelerate the failure of other components.

From a safety perspective, the starter system also plays a crucial role in emergencies. The main engine must be able to be started at any time, including when the ship requires rapid maneuvering to avoid collisions or other hazardous conditions. If the starter system fails at a critical moment, the safety risks to the ship and all crew on board increase significantly. This demonstrates that starter system reliability is not only technical but also directly related to operational safety.

Given the importance of this function, preventive maintenance is essential to ensure the starter system remains in optimal condition. Structured and regular maintenance can detect signs of damage early, prevent major disruptions, and extend the lifespan of components. Regularly checking battery voltage, terminal cleanliness, cable tightness, solenoid condition, and starter motor performance are fundamental steps an engine officer must perform. Proper preventive maintenance can maintain starter system performance, ensuring the main engine remains ready to operate safely, efficiently, and on time.

Analysis of Starter System Faults

Observations showed that the starter system experienced several recurring faults that affected the starting process. The most common fault was the starter motor not turning or turning very hard. This finding was primarily related to the physical condition of the starter motor, which was experiencing wear on the brush housing and armature shaft. This wear caused excessive friction between the armature and field coil, forcing the starter motor to draw more current from the battery. This condition not only made the starter work harder but also accelerated the drop in battery voltage, making starting more difficult. Another problem that emerged was weak battery power due to intensive use without regular inspection of the electrolyte and terminal condition. Starter system batteries typically operate under high temperatures and strong vibrations, so dirty or corroded terminals increased electrical resistance. This caused unstable current flow to the solenoid and starter motor. This weak electrical flow was further exacerbated by loose or frayed positive and negative cables, which were often found to be due to engine vibrations from long hours of daily operation. This instability caused the starter to turn only occasionally or to stop completely. Solenoid failure was also a significant fault encountered. The solenoid, which connects the main power supply from the battery to the starter motor, often malfunctions due to blackened terminals, broken cables, or repeated small sparks. A damaged solenoid prevents the starter motor from receiving the main power supply, preventing initial rotation. Overall, this combination of electrical and mechanical problems indicates a lack of optimal preventive maintenance prior to the study.

Impact of Disturbances on Starter System Performance

Disruptions to the starter system directly impact the main engine's ability to reach the initial revs required for combustion to occur. When the starter motor is running hard or slow, the engine takes longer to start. This condition forces the battery to supply current for a longer duration than normal. Batteries themselves are only designed to provide high current for a short period of time (high current - short duration), so extended use causes the battery voltage to drop rapidly. The voltage drop during cranking weakens the current flowing to the starter motor, making subsequent attempts more difficult and potentially causing total failure. If this condition occurs repeatedly, the battery enters a state of deep discharge, significantly shortening its lifespan.

An unstable starter also increases the risk of incomplete combustion during initial start-up. When the revs are not fast enough, the air entering the combustion chamber is not optimally compressed, resulting in incomplete combustion. This condition can cause symptoms such as misfiring, backfire, or vibration in the engine block during initial start-up. These abnormal vibrations not only place additional stress on the starter system but can also affect the mechanical integrity of other engine components such as brackets, engine mounts, and fuel lines.

The crew's lack of knowledge regarding the internal condition of starter components, such as brushes and armature, exacerbates the situation. Internal components like carbon brushes wear gradually and are often undetectable without disassembly. Minor brush wear reduces the starter motor's ability to deliver current to the armature, resulting in a gradual decrease in torque and rpm. If ignored, the damage can worsen and affect the coils inside the starter motor. This increases current demand, exacerbates the load on the battery, and slows the starter's rotational speed.

Another noticeable impact is increased temperature in the cables and terminals due to unstable current flow. High resistance in corroded terminals or loose cables causes electrical energy to be wasted as heat. In some cases, excessive heat can cause insulation melting, terminal blackening, and even sparking. This not only reduces the quality of current flow to the starter but also increases the risk of local short circuits. A short circuit in the starter cable or solenoid is a serious threat because it can cause a complete disruption to the engine's electrical system and the risk of a small fire in the engine room, potentially endangering safety.

Operationally, disruptions to the starter system result in inefficient and unpredictable engine starting. Delayed starting can disrupt sailing schedules, especially on passenger ships with fixed departure times. If the engine requires multiple attempts to start, battery energy consumption increases, and the crew must wait for the alternator to recharge after the engine starts. This reduces operational efficiency and increases the risk of a failed start on the next attempt, especially if the ship must stop temporarily in an emergency or after a specific maneuver.

Overall, disruptions to the starter system not only affect the starting performance of the main engine but also impact safety, operational reliability, and maintenance costs. If disruptions are left untreated without proper preventive measures, component damage will continue to increase and can ultimately lead to a more severe and dangerous system failure. Therefore, regular monitoring and preventive maintenance are essential to ensure the starter system operates optimally, stably, and safely at all times.

Effectiveness of Preventive Maintenance

The implementation of preventive maintenance during the study demonstrated a significant performance improvement in the main engine's starter system. Prior to maintenance, the starter system frequently experienced problems such as heavy revving, rapid battery voltage drops, and inconsistent starter response. Through a series of scheduled maintenance actions, starter performance gradually improved and demonstrated more stable results during various engine start-up trials.

The effectiveness of the maintenance was most evident in the battery component. Regular inspection and topping up of the battery water successfully restored the electrolyte condition to the ideal range. A hydrometer was used to monitor the electrolyte density, allowing the engine crew to ensure the battery was ready to provide a high starting current. Cleaning the battery terminals from rust and oxide also significantly impacted voltage stability. Before cleaning, dirty terminals caused high contact resistance, thus limiting the starter's energy output. After cleaning and tightening the connections, the battery voltage became more stable both at idle and during cranking. The previously drastic voltage drops now occurred within reasonable limits, allowing the starter to receive sufficient current to produce optimal starting torque.

Maintenance of the starter dynamo had a very visible technical impact on the smooth running of the motor. By cleaning the internal components of the dynamo, including the brushes, armature, and other mechanical components prone to wear, frictional resistance can be significantly reduced. Checking the bearings and lubricating the shaft also helps ensure that the starter dynamo is not operating under stress. As a result, the starter motor can rotate more smoothly and responsively. The previously high current demand due to excessive friction is now reduced, so the battery no longer experiences a large voltage drop during starting. The practical impact of this is that the engine can start more quickly and requires fewer attempts.

Maintenance of the solenoid also contributes significantly to the effectiveness of the starter system. Solenoids that previously suffered from blackened terminals and damaged connections can now function properly after cleaning and repairing. With the solenoid functioning optimally, the primary current from the battery can flow unimpeded to the starter motor. The effect is that the starter can receive a high current supply instantly and produce strong rotation from the first attempt. This reduces the need to repeatedly press the starter button, which previously accelerated battery deterioration.

The wiring of the electrical system also shows significant improvement after repairs. Loose cables create additional resistance and voltage fluctuations, which often cause starting problems. After tightening and replacing any frayed or worn cables, the electrical flow became more stable. Terminals that had previously been hot during starting were now in normal condition, indicating that the current was flowing without excessive resistance. This not only improved starter performance but also extended the lifespan of other electrical components.

Overall, preventive maintenance significantly improved the performance of the main engine starter system. Starting speed increased, current requirements decreased, and battery voltage stability was maintained. Furthermore, the frequency of previously frequent interruptions has decreased dramatically, demonstrating the critical role of preventive maintenance in maintaining ship operational reliability. With regular implementation, preventive maintenance not only prevents further damage but also contributes to time efficiency, cost efficiency, and overall operational safety.

Implications of Preventive Maintenance Implementation on Ship Operations

The implementation of preventive maintenance on the starter system has a significant impact on the smooth operation of the ship. An optimally functioning starter system ensures that the main engine can be started quickly, stably, and consistently whenever required. The speed and reliability of this process are crucial for passenger ships operating on a fixed sailing schedule. A delay in starting the engine, even a few minutes, can directly impact the departure schedule, passenger comfort, and the level of confidence in the ship's services. With improved starter response and reduced starting time after preventive maintenance, the engineer can prepare for departure more efficiently without unexpected disruptions.

A reduction in the frequency of disruptions is one of the most visible immediate impacts. Before maintenance, problems such as heavy starter cranking, rapid battery drain, and solenoid failure were common, creating uncertainty in the engine starting process. After implementing scheduled preventive maintenance, these disruptions decreased drastically. The reduced number of disruptions not only improved operational efficiency but also reduced the risk of ship downtime. When the engine can start without the need for restarts, battery power consumption is also lower, resulting in extended battery life and reduced component replacement costs.

Improving safety is also an important implication of preventive maintenance. A malfunctioning starter system poses a serious threat, especially when the ship requires rapid maneuvering to avoid danger or when the engine needs to be restarted suddenly in an emergency. By ensuring that every starter component—battery, solenoid, cables, and starter motor—is in prime condition, the crew can be assured that the main engine can be started whenever needed. This serves as part of an operational risk mitigation system that increases engine readiness in critical situations.

Furthermore, preventive maintenance can prevent chain failures. Components such as cables, terminals, and batteries are interconnected in a system that influences each other. If one component experiences problems such as corrosion or wear, the rest of the system will work harder, accelerating the breakdown. By regularly maintaining all components, the probability of systemic failure can be reduced. For example, clean and tight cables can prevent local short circuits that can damage the wiring system, while a well-maintained battery prevents sudden voltage drops that could potentially damage the alternator or other electronic components. In other words, preventive maintenance not only maintains the reliability of the starter system but also reduces the risk of major, costly breakdowns.

From an operations management perspective, preventive maintenance significantly supports the consistency of sailing schedules. Ships with reliable engine systems are unlikely to experience delays due to technical issues. This improves the quality of service to passengers, minimizes complaints, and strengthens the reputation of the ship operator. Furthermore, scheduled maintenance practices improve the crew's ability to detect early signs of damage, enabling them to take corrective action before a major failure occurs.

Taken together, these benefits demonstrate that preventive maintenance not only improves the technical performance of the starter system but also strengthens operational stability, reduces long-term costs, and enhances ship safety. Furthermore, preventive maintenance serves as a risk mitigation system, reducing the likelihood of main engine failure at critical moments. To strengthen these mitigation efforts, a systematic risk analysis of each potential fault in the starter system is required. This analysis serves as the basis for developing preventive mitigation measures that can help the crew manage risks more effectively.

Based on field observations, interviews with engine officers, and evaluations of starter component performance, several key risks that can impact the successful start-up of the main engine have been identified. These risks involve mechanical, electrical, and procedural aspects, and each has varying degrees of impact on the safety, efficiency, and sustainability of ship operations. Therefore, a Main Engine Starter System Risk Mitigation Plan has been developed, summarizing the risks, causes, impacts, risk levels, and recommended preventive mitigation measures to ensure the system's continued optimal functioning (Table 4).

Table 4. Risk Mitigation for the Main Engine Starter System

Primary Risk	Cause	Impact on Vessel Operation	Risk Level	Preventive Mitigation Measures
Starter does not rotate	Weak battery; dirty terminals; faulty solenoid	Main engine fails to start; departure delays	High	Battery voltage inspection; terminal cleaning; weekly solenoid check
Starter rotates but is heavy	Worn brushes; armature–coil friction; worn bearings	Long starting time; significant increase in battery current	High	Regular starter motor servicing; checking shaft clearance; bearing lubrication
Voltage drop during starting	Low electrolyte level; improper electrolyte density	Starter fails to turn the flywheel;	Medium –High	Weekly hydrometer check; electrolyte refill; charging system maintenance

Primary Risk	Cause	Impact on Vessel Operation	Risk Level	Preventive Mitigation Measures
		battery drains quickly		
Local cable short circuit	Cracked cable insulation; loose terminals; excessive heat	Minor fire; damage to wiring system	High	Replacement of worn cables; routine tightening; terminal heat check after starting
Solenoid fails to transmit high current	Burnt terminals; weakened solenoid coil	Starter produces a “click” sound without rotation	Medium	Terminal cleaning; replacement of worn solenoid; monthly solenoid inspection
Battery not ready for use	Incorrect charging frequency; alternator malfunction	Failure to start during emergency conditions	High	Voltage measurement after engine running; alternator output inspection
Starter cable overheating	High contact resistance; excessive current	Cable breakage risk; sudden starter failure	Medium	Cable resistance measurement; rust removal; use of standard clamps
Loss of starting capability at sea	Combined issues with battery–starter–solenoid	Vessel unable to maneuver in critical situations	Very High	Daily starter system checklist; pre-departure start test; component replacement before end-of-life
Rapid component degradation	No maintenance schedule; irregular inspections	Increased repair frequency and maintenance costs	Medium	Monthly and quarterly preventive maintenance schedule; regular logbook documentation
Operator fails to detect early signs of damage	Lack of training; unawareness of initial symptoms	Damage escalates suddenly and severely	Medium –High	Engine crew training; daily inspection SOP; visual check before starting

CONCLUSION

The results of the research indicate that the starter system plays a vital role in ensuring the continued operation of the main engine and the overall operation of the ship. Based on observations and interviews, it was found that the main problems with the starter system include starter dynamo wear, low battery power, solenoid damage, and loose or corroded cable connections. These problems cause heavy starter rotation, prolonged starting times, and even total engine failure. The implementation of preventive maintenance has proven effective in improving starter system performance. Through actions such as adding battery fluid, cleaning battery terminals, checking hydrometers, tightening cable routing, and internal maintenance of the starter dynamo and solenoid, starter system performance has shown significant improvements. Battery voltage is more stable, starter rotation is lighter, engine starting times are shorter, and the frequency of failures is drastically reduced. This maintenance also extends component life, reduces the risk of widespread damage, and minimizes emergency repair costs.

Operationally, improved starter system performance has a positive impact on ship reliability, accuracy of sailing schedules, and safety. Main engines can be started more quickly and consistently, both under normal conditions and in emergency situations. Thus, preventive maintenance not only improves the technical aspects of the starter system, but also serves as an effective risk mitigation strategy in maintaining the safety and operational efficiency of the ship.

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