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Inventory Management and Proactive Maintenance to Enhance Operational Efficiency in Excavators: Focus on Common Spare Parts Issues

Manajemen Inventaris dan Pemeliharaan Proaktif untuk Meningkatkan Efisiensi Operasional pada Ekskavator: Fokus pada Masalah Umum Suku Cadang

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Abstract

Effective inventory management and maintenance are critical for the operational efficiency of heavy equipment such as excavators. This study focuses on optimizing spare parts inventory for Cummins diesel engines using the min-max stock method. It aims to improve inventory control by categorizing spare parts into slow-moving, medium-moving, and fast-moving components and addressing maintenance issues that impact performance. The research utilized the min-max stock method to determine optimal inventory levels, ensuring spare parts availability while minimizing holding costs. Key maintenance issues in components such as track shoes, cam shafts, rear shafts, motor starters, and exhaust manifolds were identified through inspections. Advanced diagnostic tools, including vibration analyzers and thermal imaging, were used for proactive maintenance. The study identified critical wear and damage in components like track shoes, cam shafts, and exhaust manifolds, which could lead to equipment failure if not addressed. Implementing the min-max stock method helped reduce stockouts and overstocking, ensuring an optimal balance in inventory. The results demonstrate that integrating the min-max stock method with systematic maintenance practices significantly improves operational efficiency. The use of real-time diagnostic tools enabled early issue detection, reducing downtime and maintenance costs. This study emphasizes the importance of inventory optimization, regular inspections, and timely maintenance interventions for enhancing equipment reliability. Future research should explore predictive maintenance technologies to further refine inventory and maintenance strategies in the heavy equipment sector.

Keywords: min-max approach, spare parts management, damage prevention, proactive inspections, scheduled maintenance.

***SDGs*:**

Abstrak

Pengelolaan inventaris dan pemeliharaan yang efektif sangat penting untuk efisiensi operasional peralatan berat seperti ekskavator. Penelitian ini berfokus pada pengoptimalan inventaris suku cadang untuk mesin diesel Cummins menggunakan metode stok *min-max*. Tujuan penelitian ini adalah untuk meningkatkan pengendalian inventaris dengan mengkategorikan suku cadang menjadi komponen yang bergerak lambat, sedang, dan cepat serta menangani masalah pemeliharaan yang berdampak pada kinerja. Penelitian ini menggunakan metode stok *min-max* untuk menentukan tingkat inventaris yang optimal, memastikan ketersediaan suku cadang sambil meminimalkan biaya penyimpanan. Masalah pemeliharaan utama pada komponen seperti *track shoes, cam shafts, rear shafts, motor starters*, dan *exhaust manifolds* diidentifikasi melalui inspeksi. Alat diagnostik canggih, termasuk analisis getaran dan pencitraan termal, digunakan untuk pemeliharaan proaktif. Penelitian ini mengidentifikasi keausan dan kerusakan pada komponen seperti *track shoes, cam shafts*, dan *exhaust manifolds*, yang dapat menyebabkan kegagalan peralatan jika tidak ditangani. Implementasi metode stok *min-max* membantu mengurangi kekurangan stok dan kelebihan stok, memastikan keseimbangan inventaris yang optimal. Hasil penelitian ini menunjukkan bahwa integrasi metode stok min-max dengan praktik pemeliharaan sistematis secara signifikan meningkatkan efisiensi operasional. Penggunaan alat diagnostik waktu nyata memungkinkan deteksi masalah lebih awal, mengurangi waktu henti dan biaya pemeliharaan. Penelitian ini menekankan pentingnya optimisasi inventaris, inspeksi rutin, dan intervensi pemeliharaan tepat waktu untuk meningkatkan keandalan peralatan. Penelitian selanjutnya diharapkan dapat mengeksplorasi teknologi pemeliharaan prediktif untuk lebih menyempurnakan strategi inventaris dan pemeliharaan di sektor peralatan berat.

Kata Kunci: pendekatan min-max, manajemen suku cadang, pencegahan kerusakan, inspeksi proaktif, perawatan terjadwal.

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1. INTRODUCTION

Inventory management is a critical aspect of operational efficiency for companies, particularly in sectors that rely heavily on machinery and equipment (Salahudeen and A, 2018; Becerra, Mula and Sanchis, 2022). The effective management of inventory is essential not only for meeting customer demands but also for maintaining production continuity (Endler and Júnior, 2018; Shukaili, Jamaluddin and Zulkifli, 2023). This substantial investment underscores the necessity for companies to implement robust inventory management systems. Inadequate inventory levels can lead to production disruptions, resulting in financial losses and decreased customer satisfaction (Panigrahi *et al.*, 2019; Liu, Xu and Zheng, 2024). A shortage of inventory can halt production processes, hindering a company's ability to fulfill customer orders on time. On the other hand, excessive inventory may result in dead stock, which incurs storage costs and may eventually require disposal, further eroding profitability (Julius, 2024; Panigrahi, Shrivastava and Kapur, 2024). Maintaining an optimal inventory balance is crucial for ensuring smooth production operations and minimizing losses caused by poor inventory management (Shahi *et al.*, 2017; Helu *et al.*, 2020). Inadequate inventory levels can lead to production disruptions, resulting in financial losses and decreased customer satisfaction (Panigrahi *et al.*, 2019; Liu, Xu and Zheng, 2024). A shortage of inventory can halt production processes, hindering a company's ability to fulfill customer orders on time. On the other hand, excessive inventory may result in dead stock, which incurs storage costs and may eventually require disposal, further eroding profitability (Julius, 2024; Panigrahi, Shrivastava and Kapur, 2024). Maintaining an optimal inventory balance is crucial for ensuring smooth production operations and minimizing losses caused by poor inventory management (Shahi *et al.*, 2017; Helu *et al.*, 2020).

In the context of heavy equipment, spare parts are vital for routine maintenance and unexpected repairs. The performance and reliability of equipment, such as Cummins Isuzu diesel engines, heavily depend on the availability of the necessary spare parts. Recognizing these challenges, improvements were initiated in the maintenance management system for excavator units in late 2015. The aim of these enhancements was to ensure that all equipment remained operationally ready, focusing on maintenance processes that include daily inspections, periodic servicing, and comprehensive overhauls.

This study specifically examines the optimization of spare parts inventory management for Cummins diesel engines using the min-max stock method. The advantage of this method lies in its simplicity and effectiveness. By determining optimal minimum and maximum stock levels, as well as reorder points, the min-max method provides a systematic approach to balancing inventory. It ensures that spare parts are available when needed, without overstocking, which reduces holding costs and minimizes waste. Furthermore, this method allows for the consideration of essential factors such as demand planning, safety stock, lead times, and order frequencies, leading to more accurate and responsive inventory decisions. The use of the min-max method in this research offers a practical solution for improving inventory control, optimizing costs, and ensuring continuous equipment operation.

Previous studies have demonstrated the effectiveness of the min-max method in various contexts. For instance, Fatroni et al. applied the min-max inventory control model in the automotive industry, highlighting its role in reducing stockouts and optimizing inventory levels (Fatroni, Saragi and Widyastuti, 2024). The min-max approach in managing spare parts for manufacturing equipment, resulting in significant cost savings and improved service levels. The research by Hematabadi and Foroud also supports the use of the min-max method, showing its effectiveness in balancing inventory costs and service quality in the electronics sector (Hematabadi and Foroud, 2019).

By addressing these critical aspects of inventory management, this research aims to provide valuable insights into best practices that can lead to improved operational efficiency, reduced costs, and enhanced service delivery in the heavy equipment sector. Unlike previous studies, which primarily focused on specific industries such as manufacturing, automotive, and oil and gas, this study uniquely emphasizes the application of the min-max stock method specifically for spare parts inventory management in Cummins diesel engines. While earlier research has demonstrated the effectiveness of the min-max method in various contexts, this study delves deeper into the nuances of demand planning, safety stock, lead times, and order frequencies tailored to the heavy equipment sector. The outcomes of this study will contribute to the broader understanding of effective inventory management strategies in an increasingly competitive market, providing a targeted approach that addresses the unique challenges faced by companies operating in this field.

2. METHODOLOGY

2.1. Materials

In this study, various materials were utilized to effectively address the inventory management and maintenance issues associated with excavator units. The primary materials included essential spare parts for the Cummins diesel engine, which comprised cam shafts, track shoes, rear shafts, motor starters, and exhaust manifolds. These components were selected based on their critical roles in engine performance and operational reliability. Each part was sourced from reputable manufacturers to ensure high quality and compatibility with the existing systems. Additionally, maintenance tools such as torque wrenches, socket sets, and specialized hand tools were employed to facilitate disassembly and assembly of engine components. Diagnostic equipment, including multimeters and exhaust gas analyzers, was also used to assess electrical connections and exhaust emissions, ensuring compliance with performance standards.

Figure 1 illustrates the research methodology process, encompassing materials and tools identification, demand analysis and inventory management, excavator inspection and measurements, maintenance scheduling and training, advanced diagnostics and implementation, and outcome evaluation.

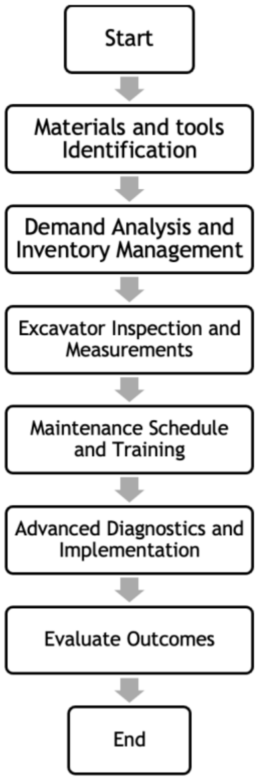

Figure 1. Flowchart of the methodology.

2.2. Method

The method employed in this study was systematic and multifaceted, focusing on both inventory management and maintenance procedures. The first step involved conducting a comprehensive demand analysis to forecast the required spare parts for the scheduled maintenance cycles. Historical usage data, maintenance logs, and failure reports were collected and analyzed to determine the frequency of component replacements and identify critical spare parts needed for the upcoming maintenance activities.

To maintain optimal inventory levels, the min-max stock method was utilized. This approach involved setting minimum and maximum stock thresholds for each critical component, ensuring that spare parts were readily available while minimizing excess inventory costs. Regular inventory audits were conducted to track stock levels and reorder items as necessary, thus preventing delays in maintenance due to parts unavailability.

Once the necessary materials were identified, a thorough inspection of the excavator units were performed. This inspection involved assessing the condition of key components, measuring wear levels using calipers and micrometers, and identifying any misalignments or failures. Each component, including cam shafts, track shoes, rear shafts, motor starters, and exhaust manifolds, was carefully evaluated for signs of wear, damage, and corrosion. Specific measurements were taken to ensure that components met the manufacturer's specifications, with a focus on identifying critical thresholds that warranted immediate replacement.

A detailed maintenance schedule was then established, outlining routine inspections, lubrication protocols, and specific timelines for replacing worn parts. This schedule included daily, weekly, and monthly checklists tailored to the operational demands of the excavators. Training sessions for maintenance personnel were also conducted, emphasizing the importance of proper maintenance practices, such as recognizing early signs of wear and implementing preventive measures.

Additionally, the study incorporated advanced diagnostic techniques. Tools like vibration analyzers and thermal imaging cameras were utilized to monitor the condition of critical components in real-time, allowing for proactive maintenance interventions. By integrating these methods and materials, the study aimed to enhance the efficiency and effectiveness of the maintenance management system, ultimately improving the reliability and performance of the excavator units while reducing operational costs associated with equipment failures and inventory mismanagement.

3. RESULTS AND DISCUSSION

The analysis of the diesel engine spare parts identified three distinct categories: slow-moving parts, medium-moving parts, and fast-moving parts. This classification is crucial for effective inventory management and has implications for operational efficiency.

3.1. Track Shoe Trouble

Track Shoe Trouble is shown in Figure 2. During the inspection and overhaul of the excavator units, several significant issues concerning the track shoes were identified.

Figure 2. Track shoe trouble.

The analysis revealed that the track shoes exhibited considerable wear and damage, with many components showing signs of cracking and deformation. Measurements indicated that the wear depth of the track shoes exceeded the manufacturer's recommended limits by approximately 2 mm, which can lead to reduced traction and stability during operation. Such deterioration not only affects the performance of the excavator but also poses safety risks during heavy operations.

In addition to wear, the alignment of the track shoes was found to be misaligned, which can lead to uneven wear patterns and increased strain on the undercarriage. This misalignment was attributed to prolonged exposure to harsh working conditions, including abrasive surfaces and heavy loads. The inspection also noted that several track shoe bolts were loose or damaged, further exacerbating the alignment issues and increasing the likelihood of track failure during operation.

The findings suggest that inadequate maintenance practices contributed to the observed track shoe troubles. Regular inspections and timely replacements of worn components are essential to ensure optimal performance and safety. The analysis highlighted the need for better monitoring of track conditions, including implementing a schedule for routine checks to identify wear and misalignment early.

To address the identified track shoe problems, several corrective actions are recommended. First, a comprehensive replacement program for severely worn or damaged track shoes should be initiated. Investing in high-quality replacement parts designed for the specific operating conditions of the excavators will enhance durability and performance. Additionally, implementing a more rigorous maintenance schedule that includes frequent inspections of track shoe wear and alignment can help prevent similar issues in the future. Training maintenance personnel to recognize signs of wear and proper alignment techniques will further improve maintenance outcomes.

Furthermore, adopting advanced monitoring technologies, such as wear sensors, could provide real-time data on track shoe conditions, allowing for proactive maintenance actions before failures occur. By taking these steps, the reliability and efficiency of the excavator units can be significantly improved, leading to enhanced operational productivity and safety on job sites. The integration of effective maintenance practices and monitoring systems will not only reduce downtime due to track shoe failures but also lower overall operational costs, thereby optimizing project execution.

Track shoes experience significant stress due to constant contact with abrasive surfaces. Over time, this leads to wear, reducing their effectiveness and potentially resulting in costly downtime. The primary causes of wear include material fatigue (Fachrizal and Suryo, 2018; Rusiński *et al.*, 2018; Suryo *et al.*, 2018). Repeated stress cycles lead to micro-cracking in the shoe material, compromising structural integrity. Besides that, environmental factors exposure to moisture, dirt, and extreme temperatures can accelerate deterioration. In particular, jobs in muddy or sandy conditions exacerbate wear.

Proper alignment and tension are crucial for the longevity of track shoes. Misalignment can cause uneven wear, leading to premature failure. Key factors influencing alignment include installation quality and tension calibration. Track shoe issues can severely hinder operational efficiency. Worn or misaligned shoes may lead to reduced traction and increased fuel consumption. Track shoe failures can pose safety risks on construction sites (Rusiński *et al.*, 2018).

Implementing a schedule for regular inspections is essential to identify early signs of wear and misalignment. Inspections should focus on visual wear assessment and alignment checks. Track shoe trouble represents a significant challenge in heavy equipment operations, impacting both efficiency and safety. By implementing comprehensive inspection routines, replacement protocols, and operator training, companies can effectively manage track shoe wear and ensure optimal machinery performance. Future research should focus on material innovations and enhanced tracking technologies to further improve the durability and performance of track shoes in demanding environments.

3.2. Cam Shaft Trouble

Camshaft trouble is shown in Figure 3. During the comprehensive overhaul of the Cummins diesel engine, several critical issues regarding the cam shaft were identified. Detailed measurements revealed substantial wear on the cam shaft lobes, with a reduction in cam profile averaging 0.5 mm compared to manufacturer specifications.

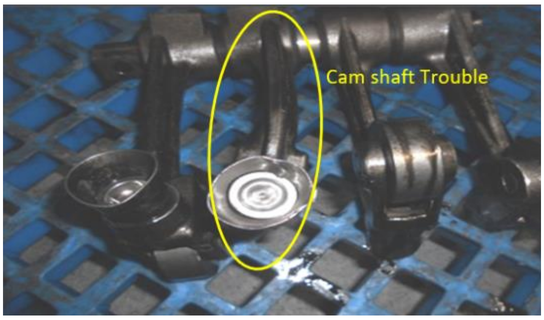

Figure 3. Cam shaft trouble.

This wear was likely attributed to prolonged use and inadequate lubrication. Additionally, inspections showed that the clearance between the cam shaft and its followers exceeded acceptable limits, measured at 0.3 mm over the recommended specifications. Such misalignment can lead to increased friction, further accelerating wear on both the cam shaft and the follower components.

An assessment of the oil passages indicated significant blockages due to sludge accumulation, with approximately 30% of the oil flow restricted. This compromised the lubrication efficiency essential for optimal cam shaft operation. Furthermore, a notable increase in mechanical noise was recorded during engine operation tests, attributed to the deteriorating condition of the cam shaft. This noise not only signifies potential failure but also indicates inefficiencies that could impact overall engine performance.

Based on these findings, several spare parts were deemed necessary for corrective action, including new cam shafts, lifters, and followers. Given the extent of wear, replacing the cam shafts was essential, while the lifters and followers needed replacement to ensure proper function and alignment. Improved oil filtration systems were also recommended to prevent future sludge buildup.

The implications of cam shaft problems on engine performance are significant. The observed wear directly correlates with reduced power output and efficiency, hindering the operational capabilities of excavators. This degradation can slow project timelines and increase operational costs due to decreased productivity. Moreover, the increased wear leads to a higher frequency of maintenance activities, raising overall maintenance costs and necessitating a proactive approach to monitoring and replacing worn components to avoid cascading failures.

Consequently, the identification of these cam shaft troubles required a revision of maintenance schedules, prioritizing regular inspections for cam shaft wear and lubrication status to detect issues early. To address and prevent future cam shaft problems, several strategies are recommended. Implementing stringent lubrication protocols, including the use of high-quality oils and regular oil changes, is crucial to reducing wear and sludge accumulation. Establishing a comprehensive monitoring system for cam shaft wear and oil flow will facilitate timely detection and intervention. Additionally, enhanced training programs for maintenance personnel focusing on the importance of cam shaft care, recognition of wear signs, and effective maintenance practices will improve overall maintenance outcomes and prolong equipment lifespan. By integrating these practices, the reliability of the excavator units can be enhanced, ultimately optimizing project execution and improving productivity and cost efficiency (Khangar and Jaju, 2012).

3.3. Rear Shaft Wear

The inspection and overhaul process of the excavator units revealed critical issues related to rear shaft wear shown in Figure 4, which significantly impacts overall performance and reliability. Detailed measurements indicated that the rear shafts exhibited excessive wear, with some components showing wear levels exceeding the manufacturer's specified limits by approximately 1.5 mm. This excessive wear is primarily attributed to prolonged use under heavy loads and inadequate lubrication during operation.

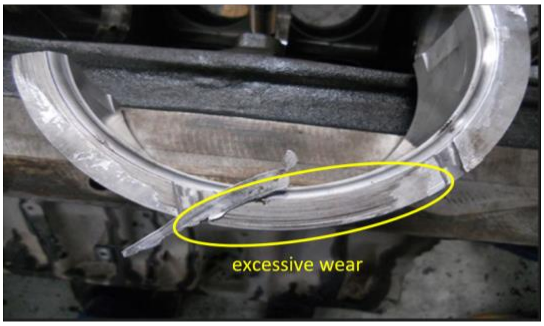

Figure 4. Rear shaft wear.

Observations from the overhaul highlighted that the surface of the rear shafts displayed signs of scoring and pitting, which can lead to increased friction and reduced efficiency. The scoring was particularly severe in areas subject to the highest stress, such as those interfacing with bearings. Such damage not only compromises the functionality of the rear shaft but also increases the risk of catastrophic failure, which could result in extended downtime and costly repairs.

Additionally, alignment issues were identified during the inspection. Misalignment of the rear shafts can lead to uneven wear patterns, further exacerbating the deterioration of the components. It was noted that several mounting points were loose, contributing to the misalignment and increasing the stress on the shafts during operation. The combination of wear and misalignment raises concerns about the long-term reliability of the excavator units and necessitates immediate corrective actions.

To address the rear shaft wear issues, several recommendations are proposed. First, a thorough replacement program for the severely worn rear shafts should be initiated, using high-quality components designed to withstand the operational demands of the excavator. It is essential to ensure that all replacement parts are compatible with the existing systems to maintain optimal performance.

Moreover, implementing a more stringent maintenance schedule focused on lubrication practices is critical. Regular oil changes and the use of appropriate lubricants will help minimize friction and wear on the rear shafts. Establishing a routine inspection program to monitor rear shaft condition, alignment, and lubrication levels can aid in early detection of potential issues, allowing for timely interventions. Training maintenance personnel to recognize signs of wear and ensure proper alignment during assembly and installation is another vital step. Enhanced training can lead to improved maintenance practices and reduce the risk of misalignment and excessive wear in the future.

Finally, incorporating advanced monitoring technologies, such as vibration analysis and wear sensors, could provide valuable insights into the real-time condition of the rear shafts. This proactive approach to maintenance can help identify emerging issues before they lead to significant failures, ultimately enhancing the reliability and efficiency of the excavator units (Zhu *et al.*, 2023). By addressing the identified rear shaft wear issues through these measures, the operational performance and longevity of the excavators can be significantly improved, leading to greater productivity and reduced maintenance costs over time.

3.4. Motor Starter Trouble

The analysis of the motor starter during the overhaul process of the excavator units revealed several critical issues impacting engine performance and reliability. Inspections indicated that the motor starters exhibited signs of significant wear and malfunction, primarily due to prolonged usage under demanding operational conditions. The most notable issues included intermittent starting failures, sluggish operation, and unusual noises during startup. Motor starter trouble is shown in Figure 5.

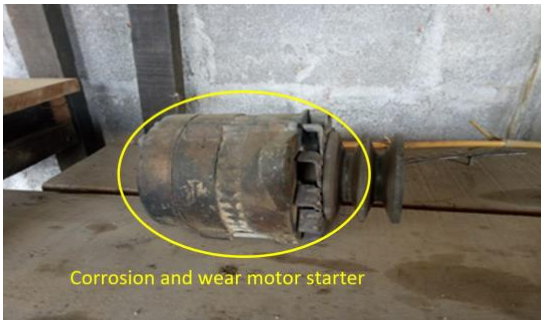

Figure 5. Motor starter trouble.

Detailed examinations showed that the internal components of the motor starter, including the solenoid and armature, displayed signs of corrosion and wear. The solenoid's contacts were found to be pitted, leading to poor electrical connections, which caused intermittent failures when attempting to start the engine. Furthermore, the armature exhibited uneven wear patterns, indicating potential misalignment during operation, which could result in increased friction and overheating.

Another critical finding was the condition of the electrical connections. Many connections were corroded, leading to voltage drops and insufficient power reaching the motor starter. This corrosion was attributed to exposure to harsh environmental conditions, including moisture and dust, which compromised the integrity of the electrical system. The combination of these issues not only impaired the starting process but also posed a risk of complete starter failure, potentially leading to costly downtime and repairs.

To address the motor starter troubles, several corrective actions are recommended. First, a comprehensive replacement program for damaged or severely worn motor starters should be initiated. Using high-quality, weather-resistant components designed for the specific operating conditions of the excavators will enhance durability and reliability. In addition to component replacement, implementing a more rigorous maintenance schedule is essential.

Regular inspections of motor starters should be conducted to identify early signs of wear and corrosion. Cleaning and ensuring tight connections can mitigate the risks associated with electrical failures. Moreover, establishing protective measures, such as using covers or seals, can help shield motor starters from environmental elements that contribute to corrosion.

Training maintenance personnel on the importance of electrical system integrity and proper starting procedures is also crucial. By enhancing their understanding of the motor starter's role and the factors that lead to failure, maintenance teams can take proactive measures to ensure reliable operation. Finally, adopting diagnostic tools, such as multimeters and oscilloscopes, can provide valuable insights into the performance of motor starters and help pinpoint issues quickly. This proactive approach allows for timely repairs before failures occur, enhancing the overall reliability of the excavator units. By addressing the identified motor starter troubles through these recommendations, the operational efficiency and reliability of the excavators can be significantly improved, ultimately leading to enhanced productivity and reduced maintenance costs (Enache *et al.*, 2019).

3.5. Exhaust Manifold Trouble

The examination of the exhaust manifold during the overhaul of the excavator units revealed several significant issues affecting engine performance and efficiency. Inspections identified that the exhaust manifolds exhibited signs of cracking and warping, which are critical concerns that can lead to exhaust leaks and increased emissions. Specifically, several cracks were observed along the joint areas, resulting in a loss of exhaust pressure and reduced overall engine efficiency. exhaust manifold trouble is shown in Figure 6.

Measurements indicated that the warping of the exhaust manifold exceeded the acceptable limit by approximately 0.4 mm, which can impair the seal between the manifold and the engine block. This misalignment not only increases the risk of exhaust leaks but also disrupts the proper flow of exhaust gases, leading to poor engine performance and potential overheating. Additionally, the presence of carbon buildup around the manifold indicated incomplete combustion, suggesting that fuel efficiency was compromised and contributing to increased emissions.

Figure 6. Exhaust manifold trouble.

Another critical finding was the condition of the mounting hardware. Several bolts securing the exhaust manifold were found to be loose or damaged, which exacerbates the likelihood of further leaks and misalignment. The lack of proper torque on these bolts can lead to vibrations and additional stress on the manifold, accelerating wear and increasing the risk of failure.

To address the identified exhaust manifold issues, several corrective actions are necessary. First, a thorough replacement program for damaged exhaust manifolds should be implemented, utilizing high-quality components designed to withstand the high temperatures and pressures associated with engine operation. Ensuring that new manifolds are properly installed and aligned will be crucial in preventing future issues. Additionally, it is essential to adopt a more rigorous maintenance schedule that includes regular inspections of the exhaust manifold and associated components. Monitoring for signs of cracking, warping, and carbon buildup can help identify problems early, allowing for timely repairs and adjustments before they escalate into more serious failures. Training maintenance personnel to recognize the signs of exhaust manifold wear and the importance of proper torque specifications during installation is also critical. Enhanced training can lead to better maintenance practices, reducing the likelihood of exhaust leaks and performance issues (Gocmez and Deuster, 2009).

Finally, incorporating advanced diagnostic tools, such as exhaust gas analyzers, can provide insights into the efficiency of the exhaust system and help detect leaks or incomplete combustion. By adopting a proactive approach to monitoring and maintenance, the reliability and efficiency of the excavator units can be significantly improved.

In summary, addressing the identified exhaust manifold troubles through these recommendations will enhance engine performance, reduce emissions, and improve overall operational efficiency. By implementing these measures, the excavator units will be better equipped to handle demanding conditions, ultimately leading to increased productivity and lower maintenance costs.

4. CONCLUSION

This study highlights the importance of integrated inventory management and systematic maintenance practices for enhancing the operational efficiency and reliability of excavator units. The use of the min-max stock method enabled optimal inventory levels, ensuring spare parts availability while minimizing holding costs. Timely maintenance interventions, based on comprehensive inspections and advanced diagnostic tools, helped identify and address wear, misalignment, and corrosion in critical components. A structured maintenance schedule, along with staff training, further supported equipment longevity and minimized downtime. By adopting these strategies, organizations can reduce costs, improve productivity, and increase equipment reliability. Future research should focus on predictive maintenance technologies to further optimize inventory and maintenance practices in heavy machinery operations.

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