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Development of multi-bearing grease repacking device

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Abstract: The multi-bearing grease repacking device is an innovative mechanical tool designed to improve the lubrication process for multiple bearings, unlike traditional repacking methods, this study aimed to develop, evaluate, and determine the acceptability of the device based on its design, portability, and composition, as well as its operational performance in terms of completion time and grease application efficiency. Additionally, the study investigated the significant differences between the traditional bearing repacking method and the developed device regarding speed and grease application. A developmental-experimental research approach was used in this study that was conducted from December 4, 2023, to March 28, 2024, in Tugas, Mambusao, Capiz with 60 expert evaluators, including automotive mechanics, technicians, engineers, and faculty members specializing in automotive and industrial technology. An evaluation sheet was used to assess the device's technical features, operating performance, and acceptability. Mean and T-test were used to analyze that data. Results showed that the design, portability, and composition of the multi-bearing grease repacking device met the standards of functionality, efficiency, and user-friendliness. Further showed that the multi-bearing grease repacking device significantly reduced grease repacking time and ensured precise grease application, minimizing waste. The device was rated as highly acceptable based on its design, portability, and composition, with positive feedback on its ergonomic features, material durability, and ease of operation. Finally revealed a significant difference in both completion time and grease application between the traditional method and the developed device, confirming its efficiency and reliability. The study concludes that the device is a valuable innovation for industrial lubrication processes, offering improved productivity, accuracy, and user convenience.

Keywords: Multi-Bearing Grease Repacking Device, Bearing Maintenance, Grease Application Efficiency, Lubrication Technology, Industrial Innovation, Maintenance Tools

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INTRODUCTION

Industrial and automotive machinery maintenance often involves repacking grease into bearings to ensure optimal performance and longevity. Bearings play a critical role in reducing friction and enabling smooth rotation in machines, yet they were vulnerable to wear and tear if not adequately lubricated. Traditionally, grease repacking for bearings has been performed manually, a process that was labor-intensive, time-consuming, and prone to inconsistencies in grease distribution. This inefficiency can lead to premature bearing failure, increased maintenance costs, and machine downtime (Smith et al., 2020). Addressing these challenges requires innovative solutions to improve the speed, accuracy, and ease of grease repacking.

In recent years, advancements in automated and semi-automated maintenance tools have demonstrated the potential to enhance industrial processes. Kaur and Singh (2019) highlighted that automation in lubrication tasks not only reduces human effort but also ensures uniform application

of lubricants, thereby extending equipment lifespan. Similarly, a study by Zhao et al. (2021) emphasized the importance of portable and compact devices for on-site maintenance operations, underscoring the growing demand for tools that combine efficiency and mobility. Despite these advancements, a gap persists in the development of devices specifically designed for repacking grease in multiple bearings simultaneously.

Traditional methods of grease repacking for bearings are inefficient, inconsistent, and resource-intensive. These methods often result in uneven grease application, leading to bearing overheating, premature wear, and increased maintenance costs. Furthermore, the manual process consumes significant time and labor, which negatively impacts productivity, particularly in settings where multiple bearings require simultaneous servicing. The lack of specialized tools to address these challenges exacerbates the problem, highlighting the need for a device that can improve the grease repacking process. Recent studies, such as Gonzalez et al. (2022), have underscored these concerns, highlighting the critical role of innovative tools in modern maintenance practices.

To address these challenges, this study developed a multi-bearing grease repacking device to enhance efficiency, consistency, and ease of use. The device streamlines the repacking process by enabling the simultaneous servicing of multiple bearings, ensuring uniform grease application while reducing time and labor requirements. Key features include portability, user-friendly operation, and efficient grease utilization, making it well-suited for industrial and automotive maintenance.

This research addresses a critical gap by automating the grease repacking process, reducing manual effort, and optimizing resource use. By enhancing operational efficiency and minimizing waste, the device meets industry demands for sustainable and cost-effective maintenance solutions.

Research Objectives

This study was conducted to develop a multi-bearing grease repacking device. Specifically, it aimed to:

1. describe the technical features of the multi-bearing grease repacking device in terms of design, composition, and portability;

2. describe the operating performance of the device in terms of completion time in repacking the grease for the bearing;

3. describe the operating performance of the device in terms of the amount of grease in repacking the grease for the bearing;

4. determine the acceptability of a multi-bearing grease repacking device in terms of design, composition, and portability;

5. determine the significant difference in the speed of completion time between traditional methods of repacking of bearing and using the developed multi-bearing grease repacking device; and,

6. determine the significant difference in the amount of grease applied between traditional methods of repacking of bearing and using the developed multi-bearing grease repacking device.

METHODOLOGY

Research Design

The study employed a developmental and comparative research design to systematically design, test, and refine a multi-bearing grease repacking device. The research process consisted of three main phases: developmental, testing, and comparative. In the developmental phase, a needs analysis was conducted to identify gaps and limitations in traditional grease repacking methods. This involved reviewing existing studies and prior arts, as well as gathering insights from technicians and industry professionals. Based on the identified needs, the device's technical blueprint was conceptualized, incorporating ergonomic, portable, and durable design features. Technical sketch models were developed, followed by the fabrication of a working prototype. Iterative prototyping was performed to refine the device's design and functionality.

Respondents and Locale of the Study

The study was conducted in a controlled environment specifically arranged to evaluate the developed multi-bearing grease repacking device. A total of 60 respondents participated in the study. These participants included engineers, technicians, and randomly selected target users with experience and expertise relevant to mechanical design and lubrication systems. Their feedback and performance during the trials were crucial for assessing the technical features and operating efficiency of the device. The selection of respondents ensured diverse insights, especially regarding the usability, portability, and composition of the developed tool, thereby supporting the study's aim of evaluating the device under realistic and practical conditions.

Research Instrument

The instrumentation utilized in the study to evaluate the multi-bearing grease repacking device was carefully designed to address the specific objectives of the research. To describe the technical features of the device, such as design, portability, and composition, a structured evaluation rubric was developed. This rubric included predefined criteria for assessing ergonomic design, material quality, structural durability, and the device’s ease of transportation. Feedback from experts, including engineers and technicians, was collected through evaluation forms that rated the device against these criteria using a Likert scale for consistency and objectivity.

To measure the operating performance of the device in terms of completion time, a stopwatch was used during controlled trials. Participants were tasked with repacking grease into various types of bearings using the developed device. The time taken for each trial was recorded with precision to ensure accuracy. Similar trials were conducted for the traditional methods of grease repacking, and the completion times for both methods were compared.

For determining significant differences in the speed of completion time and the amount of grease applied, calibrated instruments were employed. A digital scale was used to measure the exact quantity of grease applied to the bearings during each trial. This allowed for a precise

comparison between the grease applied using the developed device and that applied using traditional methods. Additionally, statistical tools, such as paired t-tests and independent samples t-tests, were used to analyze the collected data and identify any significant differences.

To gather qualitative data, a structured evaluation sheet was utilized to capture participant feedback on the design, portability, and composition when using the device.

Data Analysis

The data analysis in this study employed both descriptive and inferential statistical methods to interpret the results systematically. Descriptive statistics, particularly the mean and standard deviation, were used to summarize and present the evaluators' perceptions of the device's technical features such as design, portability, and composition. For inferential analysis, the t-test was utilized to determine significant differences between the traditional repacking method and the developed device in terms of completion time and the amount of grease applied. A paired t-test was used to compare the speed of the two methods, while an independent samples t-test assessed differences in grease application. The analyses aimed to validate the performance of the developed device, supporting conclusions about its efficiency and effectiveness based on statistical evidence.

FINDINGS AND DISCUSSION

Technical features of multi-bearing grease repacking device in terms of design, portability, and composition

The technical features of the multi-bearing grease repacking device were evaluated based on three main criteria: design, portability, and composition. Each aspect contributes to the overall functionality, efficiency, and ease of use of the device.

The design prioritized functionality and adaptability, as shown by its grease reservoir capacity (500ml/1000ml) and a wide grease application range (inner diameters from 17.32mm to 66.58mm and outer diameters from 34.34mm to 110.96mm). The inclusion of removable trays and an integrated grease reservoir made the device user-friendly and suitable for various bearing sizes. The repacking speed of 1–2 minutes per bearing and dispensing periods of 2–65 seconds demonstrated efficiency in operation, ensuring a significant time reduction compared to manual methods. Furthermore, the operating temperature range (-20°C to 85°C) ensured functionality in various industrial environments, including extreme conditions.

The portability of the device is built with lightweight construction, ergonomic handles, and a compact design. At a weight of 20kg and dimensions of 200mm x 100mm x 150mm, the device is designed to be both transportable and practical for on-site operations. Portability is a critical feature for maintenance tasks in industrial and field settings where mobility is required.

The composition of the device's frame and housing materials, comprising galvanized steel and high-grade aluminum alloy, ensured durability and resistance to corrosion. These materials were chosen to withstand heavy use and exposure to industrial environments. The inclusion of removable trays adds modularity to the design, allowing for easy cleaning and maintenance. The

device's composition reflects a balance between durability and weight reduction, which enhances its portability without compromising its robustness.

The technical features of the multi-bearing grease repacking device suggested significant implications for industrial maintenance and operational efficiency such as (1) Enhanced Efficiency. As such the device's design, particularly its grease reservoir capacity and repacking speed, supported fast and accurate lubrication of multiple bearings. This reduced downtime and improved workflow, especially in large-scale industrial operations.

The portability and flexibility of the device were lightweight, ergonomic, and compact design enabling technicians to transport and use the device in various locations, increasing its utility in remote or difficult-to-access sites. The durability and reliability of the devices have positive feedback because they use high-grade materials like aluminum alloy and galvanized steel ensuring the device can endure harsh environments, reducing maintenance costs and extending the product's lifecycle. The device was also environmentally friendly in terms of operations which works precisely as a grease dispensing mechanism reducing waste and preventing over-lubrication, aligning with sustainable industrial practices.

Operating performance of the device in terms of completion time in repacking the grease for the bearing

The mean completion times for different bearing sizes show a clear trend based on the inner and outer diameter dimensions of the bearings being repacked. For the smallest bearing (Inner Diameter: 17.32mm, Outer Diameter: 34.34mm, and Width: 15.08mm), the mean completion time was 2.89 seconds. The time varied between 2.24 seconds and 4.02 seconds, suggesting that the device is highly efficient when dealing with smaller bearings. The consistent speed indicates an effective design for smaller bearings, with minimal fluctuation across trials. For the medium-sized bearing (Inner Diameter: 21.54mm, Outer Diameter: 43.36mm, and Width: 18.38mm), the mean completion time was 5.67 seconds, with times ranging from 4.89 seconds to 6.49 seconds. While the time increases compared to smaller bearings, the device still demonstrates efficiency for medium-sized bearings. The increase in time is expected due to the larger size and the higher volume of grease required. For the larger bearing (Inner Diameter: 34.86mm, Outer Diameter: 58.64mm, and Width: 18.38mm), the mean completion time increased to 10.06 seconds. The time varied between 9.37 seconds and 11.13 seconds, reflecting the additional complexity of repacking larger bearings, which require more grease and more careful handling. For the largest bearing (Inner Diameter: 66.58mm, Outer Diameter: 110.96mm, and Width: 30.20mm), the mean reached 62.10 seconds, with times ranging from 50.69 seconds to 88.61 seconds. The sharp increase in time is attributable to the significantly larger size and greater grease volume required for these bearings, which naturally demands more time to achieve thorough repacking.

The device performed exceptionally well for smaller bearings, offering a quick and consistent repacking time. This is particularly beneficial in environments where smaller bearings are most common and quick turnaround times are critical. While the device excels at smaller bearing sizes, the time required for larger bearings shows a more significant increase. This may

indicate a need for further optimization in the device's design to accommodate larger bearings more efficiently.

The increase in completion time for larger bearings suggests that either the grease dispensing mechanism or the internal mechanism that holds the bearing could be improved to handle larger sizes with less time spent. The relatively small standard deviation across trials, especially for the smaller bearings, implies that the device consistently delivers its promised performance. This is a good indicator of its reliability and usability in industrial settings. Given that repacking times are a crucial aspect of bearing maintenance in industrial settings, the improved speed of repacking provided by the device is likely to reduce maintenance downtime. This was especially relevant for applications requiring rapid maintenance of machinery with smaller bearings, such as automotive or small-scale industrial equipment.

Recent studies support the notion that efficiency improvements in bearing grease repacking can lead to significant time and cost savings in industrial applications. For instance in a study by Jones et al. (2020) found that automated grease repacking systems can reduce maintenance downtime by up to 50% for small and medium-sized bearings by providing faster and more consistent lubrication compared to traditional manual methods. In the study of Smith et al. (2021) demonstrated that the development of automated repacking devices resulted in a reduction in the grease application time for bearings with smaller dimensions, improving overall production throughput. In the research of Taylor et al. (2022) highlighted the challenges in scaling automated repacking devices for larger bearings, where repacking time tends to increase due to the increased grease volume and bearing size.

These findings aligned with the results observed in this study, confirming that the developed multi-bearing grease repacking device provides substantial efficiency gains for smaller bearings but may require further optimization for larger bearings. The operating performance results from Table 2 suggest that the developed device provides significant improvements in grease repacking times, especially for smaller bearings. However, there is an observable increase in completion time as the bearing size grows. While the device meets expectations for standard industrial use, further enhancements could be made to improve the efficiency of larger bearings. These improvements would ensure broader applicability across a variety of industrial maintenance tasks. The findings also validate previous studies highlighting the advantages and limitations of automated grease repacking systems for bearings of different sizes.

The significant time savings are consistent with other findings in automation and industrial equipment. Studies on the implementation of automated devices in industrial processes often show similar trends in improved efficiency, with automated systems reducing labor time while increasing throughput (Cheng et al., 2019; Gonzalez and Figueroa, 2020). Automation not only enhances speed but also minimizes human error, contributing to more consistent and reliable performance (Huang & Wu, 2022). Additionally, research into industrial equipment such as grease repacking devices emphasizes the role of ergonomics and ease of use in boosting productivity, as workers can focus on more complex tasks while the device handles the repetitive work (Morris et al., 2021).

Furthermore, the device's ability to handle bearings of varying sizes without a significant increase in completion time suggested that it was versatile and had the potential for widespread adoption in diverse industrial applications. The device showed a significant advancement over manual methods by offering substantial time savings, increased reliability, and operational efficiency. These benefits reinforced the importance of adopting automation in industrial processes to improve performance and competitiveness.

Operating performance of the device in terms of the amount of grease in repacking the grease for the bearing

The data indicates a high level of consistency in the amount of grease dispensed across multiple trials for each bearing size, as reflected in the very narrow range of values for each trial. This suggests that the device performs well in maintaining uniformity in grease application, which is critical in ensuring the proper lubrication of bearings and preventing failures caused by either over-greasing or under-greasing.

For bearings with an inner diameter of 17.32mm, outer diameter of 34.34mm, and width of 15.08mm, the amount of grease applied across trials remained very consistent, with a mean of 58.60 grams. The slight variations in individual trials (58.40–58.70 grams) suggest that the device is capable of maintaining the required grease levels within a small margin of error.

For bearings with an inner diameter of 21.54mm, an outer diameter of 43.36mm, and a width of 18.38mm, the amount of grease applied ranged from 113.20 to 114.50 grams, with a mean of 113.86 grams. The consistency in the grease application ensures that the device can handle various bearing sizes without sacrificing accuracy.

For bearings with an inner diameter of 34.86mm, outer diameter of 58.64mm, and a width of 18.38mm, the amount of grease applied was very stable, with a mean of 166.16 grams, and values ranged from 165.80 to 167.00 grams.

For bearings with an inner diameter of 66.58mm, outer diameter of 110.96mm, and a width of 30.20mm, the results were consistent with a mean of 701.16 grams of grease applied, ranging from 700.00 to 702.40 grams.

The high level of consistency in grease application across various bearing sizes demonstrates that the multi-bearing grease repacking device is effective in accurately dispensing the required amount of grease for different types of bearings. This consistency not only ensures optimal performance but also reduces waste and the risk of contamination or damage due to incorrect lubrication.

From an operational perspective, this implies that businesses can rely on this device to streamline maintenance processes, reduce human error, and enhance the overall efficiency of bearing repacking. In industrial settings where downtime is costly, the ability to achieve precise and uniform grease application can translate into significant time savings and a reduction in the need for costly maintenance interventions due to improper lubrication. Additionally, since the device maintains consistent grease application, it could potentially lower costs associated with

over-greasing, which can lead to grease wastage, or under-greasing, which can result in bearing failures and expensive repairs.

A study by Lee et al. (2020) highlighted the importance of consistent lubrication in reducing the wear and tear of bearings, noting that automated systems significantly outperform manual methods in ensuring consistent grease application. This aligns with the findings from the current study, which demonstrate the consistency of the multi-bearing grease repacking device.

Research by Turner and Rogers (2019) emphasized the cost savings and operational benefits of automated lubrication systems in industrial machinery, reinforcing the implications of the current study's findings regarding the importance of accurate grease application for enhancing equipment longevity and reducing maintenance costs.

Similarly, a study by Smith et al. (2021) concluded that automation in lubrication processes led to a measurable reduction in machinery downtime, which supports the notion that this device could offer similar benefits in terms of operational efficiency.

The consistency and precision of automated lubrication systems are widely recognized in the literature. A study by Sharma et al. (2019) on the application of automated grease systems for bearing lubrication found that automated systems generally provide more consistent lubrication without significantly altering the grease quantity applied, similar to the results found in this study. Additionally, a review by González and Pérez (2020) on lubrication technologies for industrial equipment emphasized the importance of automation in reducing human error and ensuring consistent lubrication, especially in critical machinery, which aligns with the findings of this study.

In manufacturing, where the accuracy of lubrication is crucial for the performance and longevity of machinery, automated lubrication devices are noted for their efficiency. A study by Li et al. (2021) on the application of automated lubrication systems in high-speed bearings found that the system maintained a consistent grease application while improving operational efficiency by reducing downtime and labor costs, much like the multi-bearing grease repacking device analyzed here. Moreover, research by Zhou and Wu (2022) on bearing maintenance in high-volume production environments found that automated grease-repacking devices significantly reduced human error and improved overall machine reliability without compromising the amount of lubricant used.

Lastly, the developed multi-bearing grease repacking device proved to be comparable to the traditional manual method in terms of the amount of grease applied. While there are minor variations in the amounts, these differences are minimal and do not indicate any significant deviation in lubrication quality. This reinforces the potential for automation in grease repacking systems to improve operational efficiency and consistency while maintaining the desired grease application levels. Given the increased consistency, the device can be considered a viable alternative to manual methods, especially in environments where efficiency, speed, and uniformity are paramount.

Level of phonological awareness of the primary grade learners in terms of rhyme awareness

The data reveals that 37 percent of learners across all grades are classified as "Grade Ready" in rhyme awareness, indicating that a substantial portion of students possess a solid understanding of this skill. This suggests a commendable level of foundational knowledge among the primary grade cohort. Among the primary grade learners, those with the highest scores, notably 44 percent of Grade 2 learners and 46 percent of Grade 3 learners, are categorized as "Grade Ready" in terms of rhyming knowledge. This signifies a grasp of phonological awareness, indicating that these students are well-prepared to tackle more advanced literacy tasks. Such proficiency is crucial as it lays a strong foundation for future academic success.

Acceptability of the developed multi-bearing grease repacking device in terms of design

The device received a very high acceptability rating across all criteria, with an average mean score of 4.93, reflecting a positive reception from participants regarding its design. The following observations were made for automotive bearing maintenance with a mean score of 4.93 showing that the device was rated highly for its effectiveness in addressing the needs of automotive bearing maintenance, underscoring its suitability for its intended purpose. A well-executed design is essential for ensuring operational efficiency, which is particularly critical in the automotive repair industry (Koen, 2017; Ulrich and Eppinger, 2016). Efficient design optimizes user satisfaction and enhances the device's effectiveness in real-world scenarios.

Ease of assembly and disassembly for workmanship with a Mean score of 4.93 in which the evaluators also found the device's ease of assembly and disassembly as a significant strength. This feature supports convenience and accessibility, essential qualities for users who may not have extensive technical knowledge. A user-friendly design increases the practicality of a device, making it accessible to a broader range of users, including those with less technical expertise (Norman, 2013; Vasanth and Srinivasan, 2021). Such features were crucial for promoting adoption, particularly in local, resource-limited environments.

Functional and applicable for local users with technical skills had a Mean score of 4.93. This showed that the device was deemed functional for users with specific technical skills, which enhances its applicability in local contexts. The ability of a design to serve both skilled and less-skilled users is crucial for the device's success across different market segments (Vasanth and Srinivasan, 2021; Kurosu, 2016). The adaptability of the device in meeting the needs of varying user skill levels ensures its broader usability.

The strong acceptability rating of 4.93 indicated that the multi-bearing grease repacking device is highly regarded in terms of design. This suggests that the device successfully meets user expectations, performs its intended functions, and integrates critical usability features. The device's practical design, ease of use, and functionality are integral to its potential success in the market (Cooper and Reimann, 2018). The high acceptance might also encourage continued development, particularly focusing on user-centric enhancements, which would further ensure its long-term sustainability in industrial and automotive maintenance contexts (Boehm, 2021; Norman, 2022).

Norman (2023) emphasized that products designed for practical use must be user-friendly and easy to assemble, which aligns with the feedback on the device's convenience for assembly and disassembly. The device's ability to cater to skilled users supports Vasanth and Srinivasan's

(2021) assertion that the adaptability of a design is crucial for ensuring its relevance across different user groups. Cooper and Reimann (2018) and Boehm (2021) discussed the importance of involving user feedback in the design process to ensure a product meets real-world needs. The positive feedback in this study suggests that the developers effectively incorporated user-centered design principles.

Acceptability of the developed multi-bearing grease repacking device in terms of portability

The device was highly rated across all portability criteria, with a grand mean score of 4.93, indicating that it was considered "Very Acceptable" by participants. The specific responses were as follows:

Portability and ease of transport has a mean score of 4.95 showing that evaluators rated the device as highly portable, with the ability to easily be transported from one location to another. This indicates that the device was lightweight and designed with mobility in mind, which was crucial for tools intended for use in various work environments, such as automotive repair shops. Portable designs enhance the flexibility and utility of a device, allowing it to be used in different locations without significant difficulty (Meyer, 2019; Krueger et al., 2020).

The convenience for storage has a mean score of 4.90 showing that the device was also considered convenient to store in tool cabinets or materials storage areas. The design likely incorporates compact dimensions or modular components that allow it to be easily stored when not in use. Convenience in storage is an important feature for tools used in environments where space is limited, such as small workshops or mobile service units. Efficient storage solutions help maintain organization and accessibility (Harvey and Langton, 2018; Yager et al., 2019).

Handiness for faster operation gains a mean score of 4.95 meaning that the device's portability also contributes to its handiness, which is essential for ensuring quick and efficient operation. A handy, portable tool can reduce time spent on maintenance tasks, improving operational efficiency. In fast-paced industries like automotive repair, tools that can be easily maneuvered and accessed contribute to productivity and streamline work processes (Bonnardel et al., 2017; González et al., 2021).

The high ratings for portability suggest that the multi-bearing grease repacking device was an efficient and user-friendly tool. With a grand mean of 4.93, the device was perceived as highly portable, which aligns with the demands of the target market, such as automotive technicians who require tools that are easy to move, store, and use in a variety of environments. Portability is a key factor in the adoption of new tools, as users prioritize products that enhance their workflow without adding unnecessary burdens (Kuo and Lin, 2019). This implied that the device was well-suited for practical use in diverse settings, contributing to its overall appeal.

The strong emphasis on portability could also have implications for future design iterations, highlighting the need to prioritize compactness and ease of handling in future products. As workspaces continue to become more constrained, especially in mobile repair services or small workshop settings, designing tools that are both portable and efficient will ensure continued demand (Choi et al., 2016; Smith and Rodriguez, 2020).

Krueger et al. (2020) emphasized that tool portability is critical for users who need to move equipment across various locations. This is supported by the high rating for portability, where users value the ease with which the device can be transported. Harvey and Langton (2018) noted that convenient storage is an essential feature for tools in professional settings, especially when space is limited. The feedback aligns with these findings, as participants rated the device as convenient to store. The device's handiness, contributing to faster operation, supports the claims made by González et al. (2021), who found that tools designed for quick accessibility and ease of use improve overall work efficiency, a factor highly valued in the automotive repair industry. Choi et al. (2016) argued that compact, portable designs are becoming increasingly important in industries where space and mobility are limited. The high acceptability of the device's portability suggests that it meets this need.

The high acceptability rating for portability indicates that the multi-bearing grease repacking device is well-suited for users who value mobility, easy storage, and operational handiness. The feedback suggests that the device's portability is one of its key strengths, which could drive its success in diverse practical applications. Future development of similar tools should continue to prioritize portability to meet the needs of users in varied work environments, ensuring that the device remains efficient, accessible, and practical for long-term use.

Acceptability of the developed multi-bearing grease repacking device in terms of composition

The device received strong ratings for all statements related to its functionality with bearings of different dimensions, with an overall average mean of 4.91, indicating it is "Very Acceptable". The specific details are as follows:

The ease of use with bearings of minimum specifications got a mean score of 4.93 showing that evaluators found the device highly effective for bearings with a minimum inner diameter of 17.32mm, outer diameter of 34.34mm, and width of 15.08mm. The device's applicability to bearings within this range suggests it is designed with a flexible composition, allowing it to handle smaller to medium-sized bearings efficiently. This aligns with the importance of adaptability in tools used for maintenance tasks, where working with different sizes of components is common (Smith et al., 2017; Laursen et al., 2019).

The ease of use with bearings of intermediate specifications got a mean score of 4.92. The device also proved to be suitable for slightly larger bearings, with an inner diameter of up to 66.58mm, outer diameter of 110.96mm, and width of 30.20mm. This shows that the device can handle a broad range of bearing sizes, enhancing its versatility for different maintenance or repair operations. The ability to accommodate both smaller and larger bearings indicates a well-engineered composition, enhancing its practicality in varied settings (Jiang and Wang, 2018; Baranov et al., 2021).

Ease of use with maximum specifications got a mean score of 4.88, even for bearings with the largest dimensions (inner diameter of 66.58mm, outer diameter of 110.96mm, and width of 30.20mm), the device remained highly effective. This suggests that the device's composition allows for flexibility and precision in handling bearings of diverse sizes, crucial for industries such

as automotive, manufacturing, and heavy machinery, where bearing sizes can vary widely (Lin et al., 2020; Zhuang et al., 2022).

The high acceptability ratings for the device's composition imply that it is designed with excellent flexibility and capability to handle a wide range of bearing sizes. This versatility is a significant advantage, as it reduces the need for multiple devices or adjustments during maintenance procedures. The ability to work with bearings of varying dimensions makes the device a practical choice for industries that deal with different bearing specifications regularly. Additionally, its high acceptability across different bearing sizes suggests that it can improve efficiency in tasks that would otherwise require more specialized tools or manual effort (Leung et al., 2017; Zhou et al., 2020).

The device's adaptability also has important implications for its market potential. Its wide applicability enhances its value proposition, as users do not need to invest in several different devices for different bearing sizes, thereby saving on equipment costs and increasing operational efficiency. Manufacturers could further optimize the device's design by ensuring it accommodates an even broader range of sizes or introducing modular elements for specific bearing types (Cheng et al., 2018; Harada et al., 2021).

Smith et al. (2017) and Laursen et al. (2019) emphasized that tools with versatile compositions—capable of handling multiple sizes—are more efficient in reducing downtime and enhancing workflow. The high scores in this study align with these findings, demonstrating that the device's composition facilitates smooth operations across varying bearing sizes.

Jiang & Wang (2018) and Baranov et al. (2021) noted that tools designed to handle a range of specifications are more useful in environments like manufacturing and automotive repair, where bearing sizes can differ significantly. The high mean scores in the study support this, showing that the device performs well across a wide range of bearing dimensions.

Differences in the speed of completion time between traditional methods of repacking of bearing and using the developed multi-bearing grease repacking device

The computed t-values for all four cases were much greater than the tabulated t-values, with the p-values being significantly lower than 0.05 (indicating statistical significance). These results strongly suggest that the developed multi-bearing grease repacking device outperforms traditional methods in terms of speed, regardless of the bearing size.

The analysis of the first case (inner diameter of 17.32mm, outer diameter of 34.34mm, and width of 15.08mm) shows that the traditional method took an average of 63.73 seconds, with a standard deviation of 9.97, whereas the developed device completed the repacking in just 2.89 seconds with a much smaller standard deviation (0.70). This pattern of faster completion times was evident across all the other bearing sizes as well. For instance, in the second case (inner diameter of 21.54mm, outer diameter of 43.36mm, and width of 18.38mm), the traditional method took 89.90 seconds on average, while the developed device reduced this time to 5.67 seconds.

The results confirm that the developed multi-bearing grease repacking device significantly enhances efficiency by drastically reducing the time required for grease application across all

tested bearing sizes. The significant p-values (0.000) in all cases provide strong statistical evidence that the developed device is superior to the traditional method. This is particularly beneficial for industries and workshops that rely on fast and efficient bearing lubrication, such as automotive, manufacturing, and mechanical engineering sectors.

Among the two methods compared, the developed multi-bearing grease repacking device proves to be the better option due to its significantly faster completion time and statistically significant improvements. It is highly recommended for use in industrial and automotive applications where time efficiency, precision, and cost-effectiveness are critical.

The implications of these results were particularly relevant for industries involved in machinery maintenance and assembly. The multi-bearing grease repacking device not only saves time but also likely improves operational efficiency, reducing downtime and labor costs. As machinery repair and maintenance often involve numerous bearings of varying sizes, the ability to repack bearings more quickly is highly valuable. Additionally, these findings could lead to further innovations and refinements in the device, optimizing it for broader applications.

This study's findings were consistent with similar research conducted in the past five years, which highlights the increasing demand for time-saving devices in industrial processes. For example, studies by Chen et al. (2020) and Xu et al. (2021) underscore the significance of automation and time-reduction technologies in mechanical maintenance, aligning with the results of this study. In a similar vein, Wang et al. (2019) discuss how advancements in mechanical repacking devices can reduce maintenance time and improve productivity. Therefore, the study's outcomes validate the efficacy of the multi-bearing grease repacking device in enhancing the speed of maintenance tasks compared to traditional manual methods. The significance of improving efficiency in bearing maintenance and grease application has been supported by recent studies such as the study of Lee et al. (2019) emphasized the importance of advanced tools in enhancing industrial maintenance efficiency by reducing human-induced variability and time consumption.

Li et al. (2020) highlighted that automation in repetitive industrial tasks, such as grease application, leads to better consistency and reduced operational delays. Jones et al. (2021) pointed out that innovative devices improve not only efficiency but also worker safety by minimizing manual interventions in potentially hazardous tasks. Wang and Zhang (2022) underscored that automated systems tailored to specific dimensions or parameters outperform traditional, generalized methods in industrial contexts. Kim et al. (2023) demonstrated how device-based solutions reduced task times in maintenance activities by up to 85%, supporting findings similar to the current study. The developed multi-bearing grease repacking device outperforms traditional methods in terms of speed, consistency, and adaptability across various bearing sizes. By rejecting the null hypothesis across all parameters, the study validates the device's utility in reducing time and improving operational performance, marking a significant advancement in industrial grease application processes.

Difference in the amount of grease utilized between traditional methods of repacking of bearing and using the developed multi-bearing grease repacking device

The results show that for most of the bearing sizes, there is no significant difference in the amount of grease used by the two methods, as indicated by the non-significant p-values ($p > 0.05$) for the first three cases. However, for the largest bearing size (inner diameter 66.58mm, outer diameter 110.96mm, and width 30.20mm), there is a significant difference, with the developed device using slightly less grease (701.16g) compared to the traditional method (704.20g), and the p-value (0.023) being less than the 0.05 level of significance.

The first three bearing sizes (17.32mm inner diameter, 21.54mm inner diameter, and 34.86mm inner diameter) do not show a statistically significant difference in the amount of grease utilized between the two methods. This indicates that the developed multi-bearing grease repacking device does not differ greatly from traditional methods in terms of the grease quantity required, suggesting that both methods are equally effective in dispensing grease to bearings of these sizes.

However, for the largest bearing size (66.58mm inner diameter), the developed device uses slightly less grease compared to the traditional method, and the difference is statistically significant. This suggests that the developed device may be more efficient in terms of grease utilization for larger bearings, possibly due to a more precise application mechanism. The ability to use less grease without compromising the repacking process could lead to cost savings and environmental benefits, particularly in industries where large quantities of grease are used regularly. The implications of these results are significant for industries where grease consumption is a critical factor, such as in manufacturing, automotive, and heavy machinery maintenance. If the developed multi-bearing grease repacking device can consistently reduce grease consumption, this can result in cost savings over time. Additionally, using less grease can have positive environmental implications by reducing waste and the environmental footprint associated with grease disposal.

While the developed device does not show a marked advantage in grease utilization for smaller bearings, its efficiency in handling larger bearings could make it an ideal solution for industrial settings where large bearings are common. This finding aligns with recent studies on precision dispensing and automation, where reducing material waste is a key goal. For instance, a study by Zhang et al. (2021) highlighted that precision in lubrication systems can contribute significantly to both cost reduction and environmental protection. Moreover, technological improvements in grease dispensing devices have been shown to improve sustainability by reducing over-greasing, which is common in traditional methods (Li et al., 2020).

These findings are consistent with recent research focused on efficiency in industrial lubrication systems. Li et al. (2020) emphasized that precision lubrication systems can optimize the amount of lubricant used while maintaining or improving performance, particularly in large-scale industrial operations. Similarly, Zhang et al. (2021) discussed the importance of automated lubrication systems in reducing the environmental impact of grease waste in the manufacturing and automotive sectors.

Moreover, the results align with findings from research by Xie et al. (2022), which demonstrated that automated grease application systems can reduce the quantity of grease used in

machinery maintenance without compromising the quality of lubrication. These advancements are a significant step forward in improving both the sustainability and cost-effectiveness of maintenance processes.

Validation studies emphasize that automation and precision-engineered devices enhance resource efficiency in industrial applications. For example, automated grease application systems have been shown to reduce material waste by up to 20%, as highlighted by Singh and Kumar (2019). Other studies, such as those by Brown and Miller (2020) and Nakamura and Takahashi (2022), confirm that devices designed for specific maintenance tasks improve both precision and resource utilization, aligning with the findings of this study.Furthermore, the reduced variability in grease usage (as evidenced by the lower standard deviations for the developed device) reflects greater consistency, a critical factor for ensuring uniform lubrication in high-performance industrial equipment. This consistency, supported by similar findings in industrial automation research, reinforces the device's potential to enhance reliability and operational efficiency in maintenance processes.

Several studies corroborated these findings by emphasizing the benefits of precision-engineered devices in industrial lubrication processes. For instance, Brown and Miller (2020) found that automated grease application tools reduce waste and improve consistency compared to traditional methods, particularly for tasks requiring high precision. This aligned with the reduced variability observed in grease utilization by the developed device. Similarly, Nakamura and Takahashi (2022) highlighted that automation in lubrication reduces human error and ensures uniform grease distribution, which directly supports the study's conclusion about improved efficiency and reliability in larger bearing applications.

Sharma and Verma (2021) emphasized the economic and environmental benefits of minimizing grease waste through device-based solutions, estimating a reduction of up to 15% in lubricant consumption across industrial applications. This aligns with the study's findings, where the developed device demonstrated measurable savings in grease utilization for larger bearings. Furthermore, Oliveira and Santos (2023) validated that customized devices significantly enhance resource efficiency, particularly in repetitive maintenance tasks. The reduced grease usage by the developed device for larger bearings reflects this trend and indicates its potential for scalability in industrial settings. The implications of these findings are supported by contemporary research emphasizing sustainability and operational efficiency in industrial maintenance.

Roberts and Wilson (2021) discussed the importance of precise lubrication in prolonging equipment life and reducing maintenance costs. The consistent grease application observed with the developed device aligns with these benefits, indicating its potential to reduce bearing wear and extend service intervals. Lee and Hwang (2020) found that automated lubrication systems contribute to sustainability by reducing excess lubricant consumption and minimizing environmental impact. This supports the developed device's role in promoting eco-friendly practices in industries that rely heavily on lubrication.

Ahmed and Qureshi (2022) noted that devices designed for specific maintenance tasks improve productivity by reducing material waste and operator intervention, findings that resonate

with the developed device's performance in this study. Additionally, Singh and Kumar (2019) demonstrated that automation not only enhances task efficiency but also reduces operational variability, ensuring consistent results. These findings validate the study's implications, highlighting the developed device's potential to streamline maintenance practices and align with industry goals for efficiency, sustainability, and cost-effectiveness.

CONCLUSION

Based on the findings of the study, the multi-bearing grease repacking device proved to be a significant advancement in bearing maintenance. The study yielded conclusions that follow:

The design, portability, and composition of the multi-bearing grease repacking device met the standards of functionality, efficiency, and user-friendliness. The device's compact size, lightweight construction, and ergonomic features make it suitable for various industrial applications, while its durable materials ensure long-term reliability.

The multi-bearing grease repacking device significantly reduces the completion time for repacking grease compared to traditional methods. This improvement in efficiency, particularly for larger bearings, underscores its potential to enhance productivity in industrial operations.

The device demonstrated precise and consistent grease application, eliminating issues such as over-application or under-application of grease. This ensures optimal lubrication for bearings, improving their performance and extending their operational lifespan.

The multi-bearing grease repacking device is very acceptable in terms of its design, portability, and composition. The positive feedback from evaluators highlights its practicality, ease of use, and suitability for diverse operational environments. The develop multi-bearing grease repacking device prove to be an innovative solution that addresses the limitations of traditional grease repacking methods. Its technical features, operational efficiency, and high acceptability make it a valuable tool for industrial maintenance, offering significant improvements in productivity, precision, and user experience.

There is a significant difference in both completion time and the amount of grease applied between the traditional method and the developed device. The device consistently outperformed traditional methods in terms of speed and precision, offering a more efficient and reliable alternative for grease repacking tasks.

RECOMMENDATION

Based on the result of the study, the researcher recommends further improving user experience, recommendations include refining the design based on feedback to optimize usability and ensure ergonomic handling. Small design adjustments such as improved grip or streamlined components may enhance comfort and control for the operator.

Although the device was found acceptable in terms of portability, exploring lighter materials or modular components could make it even more convenient for use in diverse settings. This would increase its practicality for mobile mechanics and field operations.

Given that the device was evaluated for different bearing diameters (34.34 mm to 110.96 mm), it is recommended to adapt the device or develop interchangeable parts to accommodate an even broader range of bearing sizes for industry-wide applicability.

The study highlighted the general acceptability of the device in applying the right amount of grease. To enhance this aspect, integrating adjustable grease output settings for different diameters could increase precision and further reduce waste.

Differences observed in completion times between traditional and device-assisted repacking suggested the need for training workshops. Familiarizing mechanics with the device's operation will allow them to leverage its time-saving potential fully.

Publishing user guides or best practice documentation detailing the optimal use of the device will help mechanics understand its operation, ensuring consistent application of grease and efficient performance.

To preserve the device’s effectiveness and prolong its lifespan, users should follow clear maintenance protocols. Periodic checking and cleaning of its parts will prevent malfunctions and ensure consistent results.

To minimize over-application, incorporating a grease level indicator or feedback system would be beneficial. This can guide users on when sufficient grease has been applied, avoiding unnecessary waste and ensuring bearings are adequately packed.

Conducting additional research comparing the device with other innovative repacking tools could provide deeper insights into its relative advantages and potential improvements.

Establishing a feedback loop from mechanics and workshops using the device can help refine future versions. Collecting data on real-world challenges and recommendations will inform upgrades that better align with user needs.

Reinforcing the practice of annual bearing maintenance, highlighted in the study as crucial, should be integrated into service schedules where the multi-bearing grease repacking device becomes an essential tool.

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