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Design and Construction of Special Service Tools for Forklift Wheel Bearings Lubrication Using a Pneumatic System

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ABSTRACT

Manual lubrication of forklift wheel bearings is still inefficient and inconsistent. This study aims to design and test a pneumatic-based bearing lubrication aid to improve lubrication efficiency and speed. The research method used is experimental, involving tool design and testing with air pressure variations of 2, 3, and 4 bar on bearing types 30306, 32206, and 32207. The observed parameters include lubrication time and the amount of grease supplied. The results show that increasing air pressure shortens lubrication time but reduces the amount of grease delivered. An air pressure of 3 bar is considered the most optimal condition as it provides a balance between lubrication speed and grease adequacy. Therefore, the pneumatic system is proven effective in improving the lubrication performance of forklift wheel bearings

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1. INTRODUCTION

Wheel bearings are critical components in industrial vehicles [1], such as forklifts, serving to support loads and ensure stable wheel rotation [2]. The performance and service life of bearings are significantly influenced by the effectiveness of the grease lubrication system, which must form an even lubricant film on the contact surfaces of the rolling elements [3]. Recent research indicates that uneven grease distribution can lead to increased friction, premature wear, and the risk of bearing failure in heavy-load applications [4]. Manual lubrication, which is still widely used in industry, has several limitations, including reliance on operator labor, relatively long lubrication times, and uneven grease distribution. A previous study [5] stated that irregular grease supply can cause the lubricant film thickness to become unstable. This is supported by the findings of Liang et al. [6], which show that uneven grease distribution reduces the effectiveness of lubrication in rolling bearings.

Recent studies indicate that grease distribution and lubrication performance in rolling bearings are strongly influenced by contact paths, operating conditions, and pressure control systems. Jin et al. [7] reported that the contact path of rolling elements affects grease distribution and elastohydro dynamic film thickness, which are essential for lubrication stability, while Ma et al. [8] found that lubrication characteristics in cylindrical roller bearings directly influence operational accuracy and system reliability. To improve lubrication effectiveness, pneumatic-based lubrication systems have been widely developed due to their ability to provide stable and controlled pressure. Research by Ghatiga et al [9] demonstrated that pneumatic systems improve lubrication efficiency and maintain stable grease pressure. In addition, experimental studies by Zhou et al. [10] and He et al. [11] showed that variations in air pressure significantly influence grease flow rate and lubricant film formation inside bearings, thereby affecting lubrication performance and bearing durability.

In industrial applications such as forklifts, bearing reliability has become increasingly important due to heavy operational loads and repetitive working cycles. Recent studies indicate that pneumatic and pressurized lubrication systems are effective in improving lubrication consistency and reducing maintenance requirements for heavy-duty bearings. Research by Ilmar F. Santos explains that controllable pneumatic lubrication systems can regulate lubricant pressure and flow more effectively, thereby improving bearing performance and operational stability [12]. In addition, studies by Lorenzo Maccioni demonstrate that pressurized lubrication systems are capable of producing more stable lubricant distribution and maintaining a consistent lubricating film under heavy-load conditions compared to conventional lubrication methods [13]. Therefore, the development of a pneumatic-based lubrication aid for forklift wheel bearings offers significant potential to improve maintenance efficiency, lubrication stability, and bearing service life.

2. METHOD

This research methodology employs the Research and Development (R&D) method [14] using the engineering design approach [15] to develop a prototype of a pneumatic-based lubrication aid for forklift wheel bearings [16]. The research stages include needs assessment [17], design, fabrication, testing, and performance evaluation of the device [18]. The sequence of the research stages is illustrated in the research flowchart shown in Figure 1, which describes the systematic process from initial problem identification to prototype testing and evaluation.

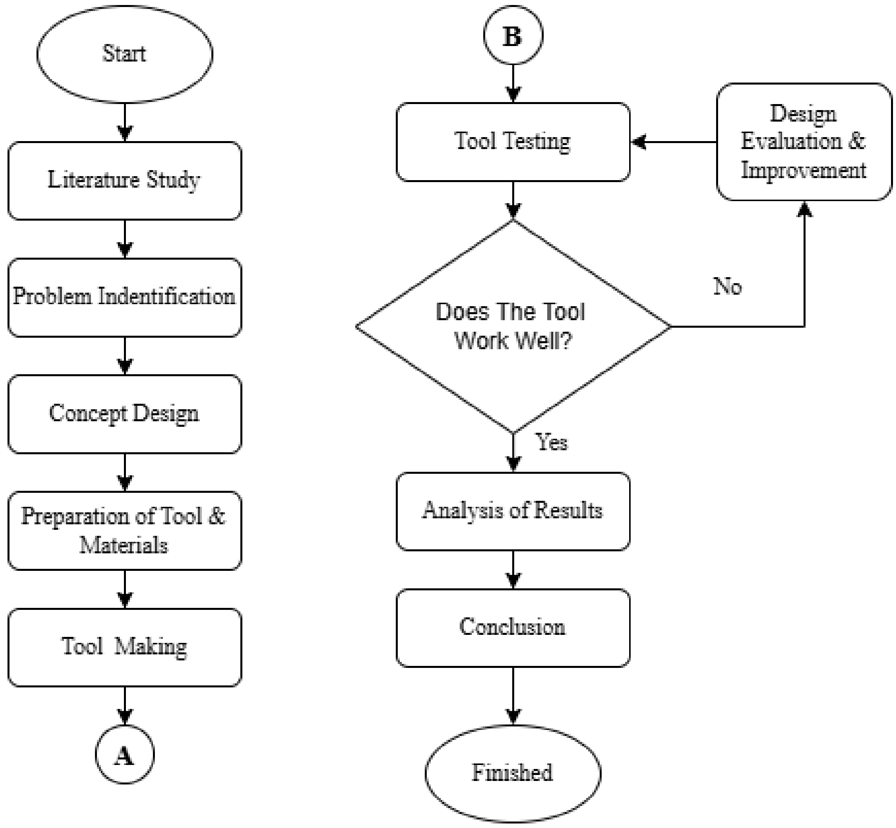
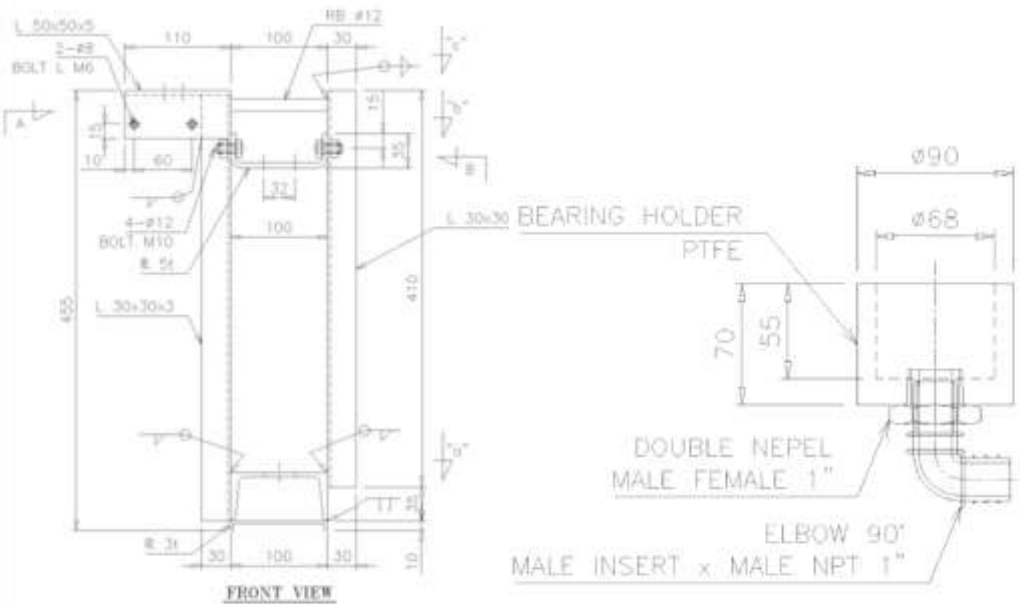


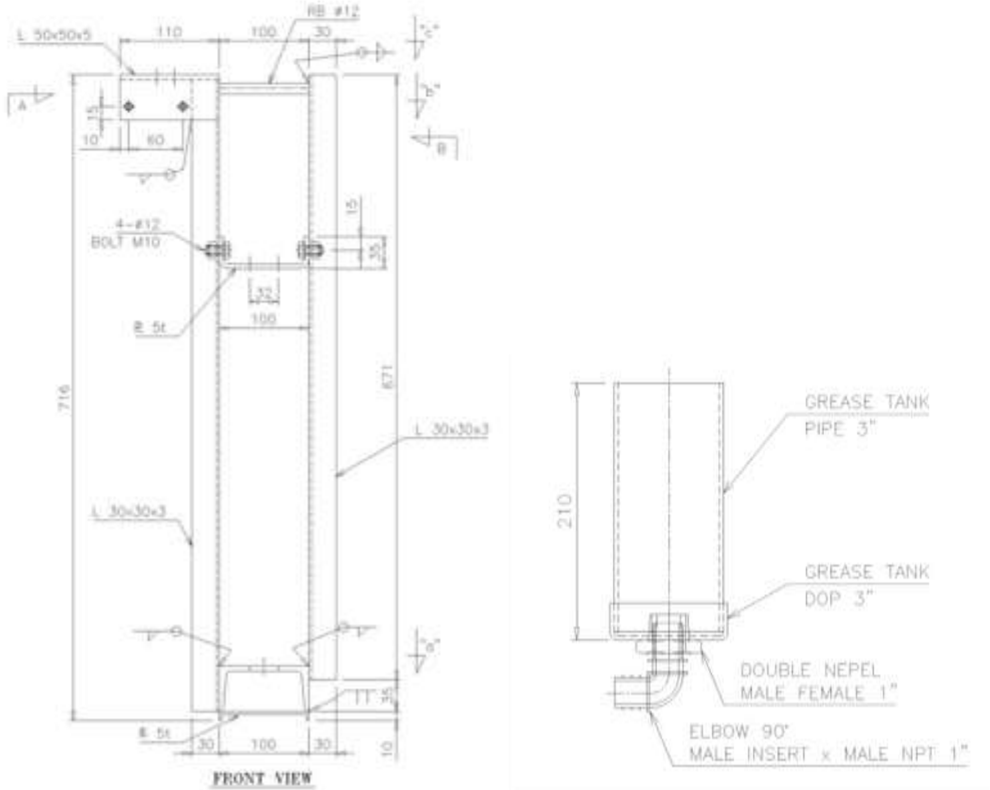
Figure 1. Research flowchart.

2.1 System Design

The tool design was created using Autodesk Inventor CAD software; the design is illustrated in the Figure 2.

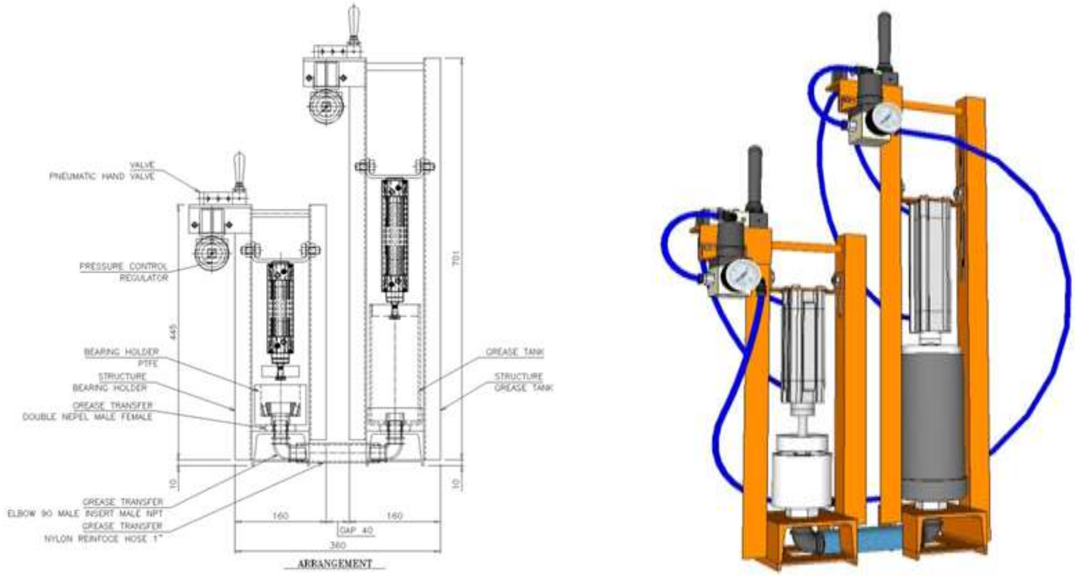


(a)



(b)

Figure 2. (a) bearing lubrication point and (b) grease reservoir.



(a) (b)

Figure 3. The (a) 2-D Design and (b) 3-D design of proposed SST.

2.2 Flow Sheet

The flowchart in Figure 4 illustrates the operational sequence of a pneumatic-based bearing lubrication system.

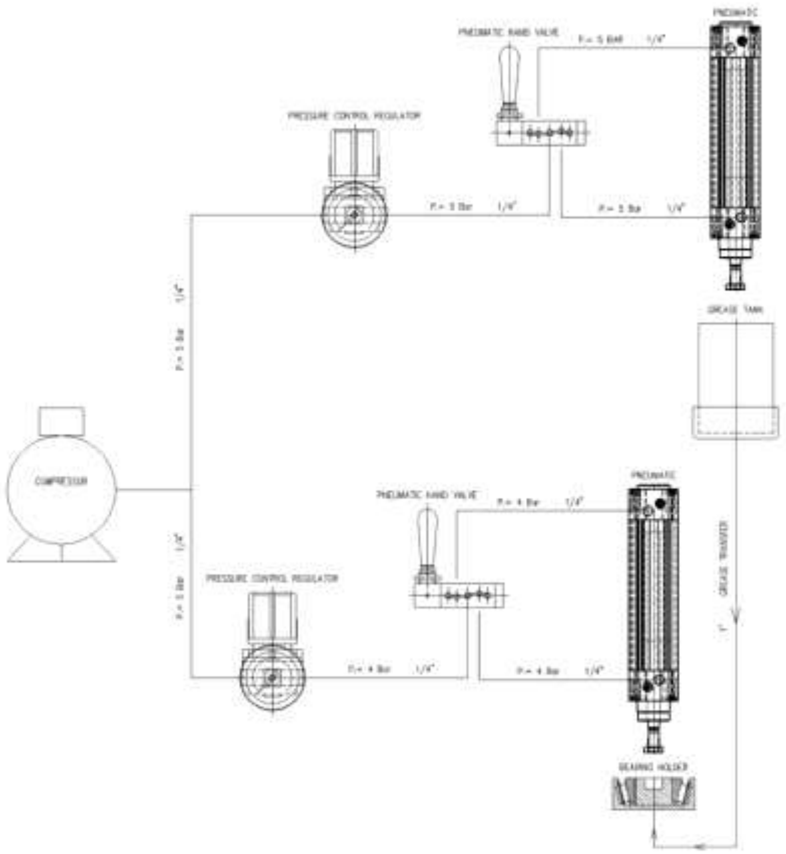


Figure 4. Flowsheet diagram.

The flowchart in Figure 4 systematically illustrates the workflow of the pneumatic-based bearing lubrication system, starting with the supply of compressed air from a compressor regulated by a pressure regulator to maintain stable pressure, which is then routed through a pneumatic control valve to the bearing-holding pneumatic cylinder and the grease-injection cylinder. This system allows grease to be evenly forced into the rolling elements of the bearing, making the lubrication process faster, more consistent, and more controlled compared to manual methods [19]. During the process, observations are made regarding lubrication time and grease distribution within the bearing to ensure the system's effectiveness [20]. The use of stable pneumatic pressure is known to improve grease flow characteristics and aid in the formation of a better lubricant film, thereby reducing direct contact between bearing components and enhancing lubrication performance [21]. This flow sheet approach also supports a more structured, consistent, and easily replicable testing process in the development of pneumatic-based lubrication aids.

2.3 Testing Method

The test was conducted to determine the effect of varying air pressure on the performance of a pneumatic-based bearing lubrication system. The test used three types of tapered roller bearings: 30306, 32206, and 32207 (Table 1). Before the test began, each bearing was cleaned of old grease residue to ensure uniform initial test conditions. The initial weight of the bearings was then measured using a digital scale with a precision of 0.01 grams. Afterward, the bearings were placed on the lubrication mount, and the pneumatic system was connected to a compressed air source.

The air pressure variations used in this study were 2 bar, 3 bar, and 4 bar (Table 1). The pressure was adjusted using a pressure regulator and monitored using a pressure gauge to maintain pressure stability throughout the lubrication process. During testing, grease was forced into the bearing using a pneumatic cylinder. Lubrication time was measured with a stopwatch, starting from when the grease began entering the bearing until the lubrication process was complete. After lubrication was complete, the bearing was weighed again to determine its final weight.

Table 1. Test data a pneumatic-based bearing lubrication system

No	Bearing Size Standard	Air Pressure of the Bearing Cylinder (bar)
1		2
2	30306	3
3		4
4		2
5	32206	3
6		4
7		2
8	32207	3
9		4

3. RESULTS AND DISCUSSIONS

3.1 Design Results

The physical prototype of the pneumatic-based forklift wheel bearing lubrication system is shown in Figure 5. The descriptions of the components are provided in Table 2.

Figure 5. Prototype of SST.

Table 2. Internal consistency reliability of biology test

No.	Component Name	Quantity	Description
1	Hand valve	2 Pcs	Pressure 8 - 15 bar
2	Pneumatic control	2 Pcs	4H210-08 (8 - 15 bar)
3	Regulator	2 Pcs	AR2000-02 (0,5 – 9,5 bar)
4	Pressure gauge	2 Pcs	Pressure 0 – 10 bar
5	Grease-press pneumatic cylinder	1 Pcs	DSBC 32X100 (max. Pressure 12 bar)
6	Pneumatic cylinder bearing presser	1 Pcs	DNCB 32X50 (max. Pressure 10 bar)
7	Grease tank	1 Pcs	PVC Ø 3”
8	Bearing lubrication area	1 Pcs	Teflon Round Bar
9	Grease transfer hose	12 cm	Thread hose Ø 1”
10	Air hose	2 m	Air hose Festo PUN-H-8x1.25-BL Ø 8mm (max. pressure 10 bar)
11	Tool focus	2 Pcs	UNP 100 x 50 mm thick 5 mm
12	Tool frame	2 Set	Angle iron 3 x 3 mm thick 3 mm

3.2 Test Results for Bearing Lubrication Equipment

As shown in Table 3, changes in air pressure affect the lubrication time and the amount of grease entering the bearing.

Table 3. Bearing Lubrication Test Results

No	Bearing Size	Bearing pressure cylinder (bar)	Bearing weight before lubrication (grams)	Bearing weight after lubrication (grams)	Weight of incoming grease (grams)	Lubrication time (seconds)
1		2	248	267	19	13,24
2	30306	3	248	265	17	09,93
3		4	248	262	14	08,96
4		2	185	195	10	09,86
5	32206	3	185	194	9	07,58
6		4	185	192	7	06,09
7		2	279	294	15	14,65
8	32207	3	279	292	13	11,43
9		4	279	291	12	09,55

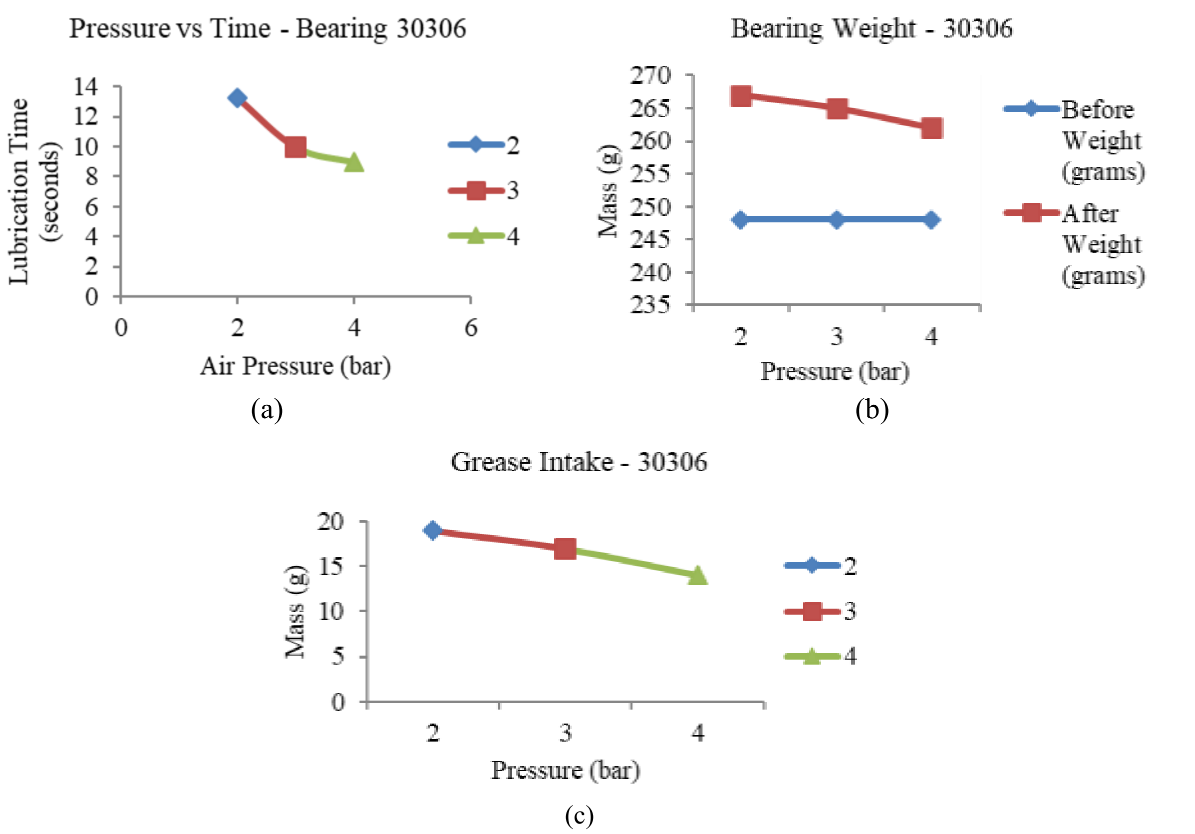
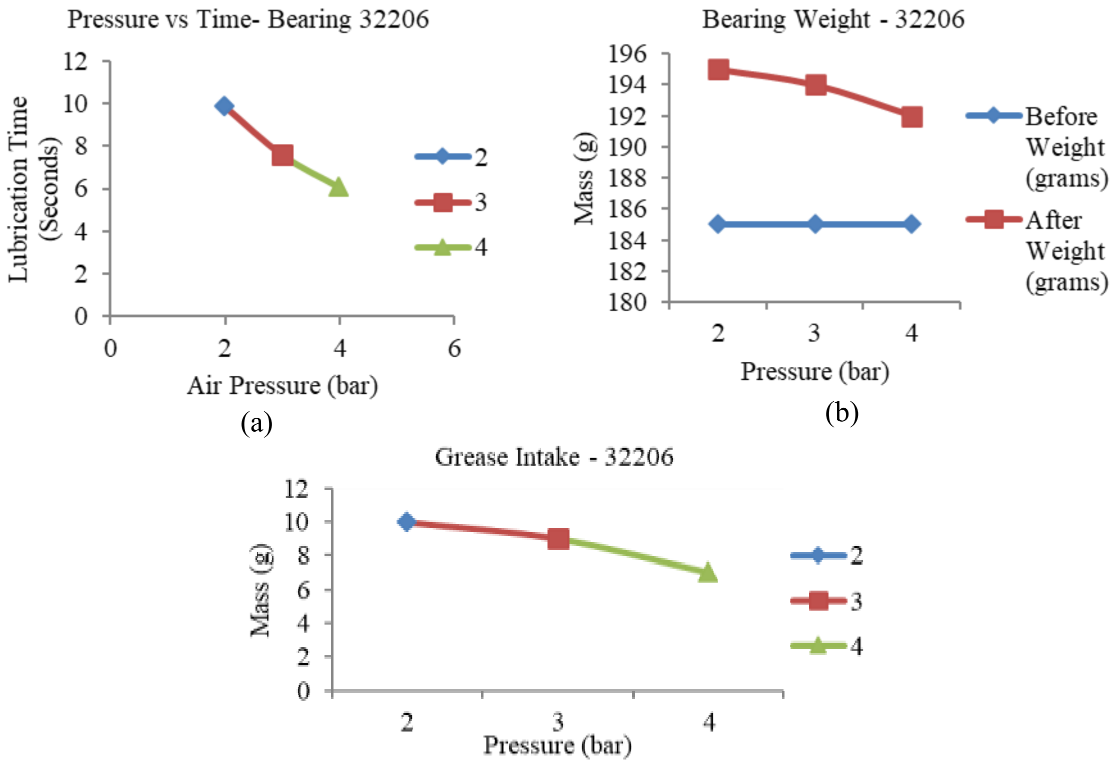


Figure 6. (a) Test results for the bearing 30306, pressure vs time, (b) bearing weight, and (c) grease intake.

The test results are in Figure 6 for bearing 30306 shows that an increase in air pressure in the pneumatic system affects the amount of grease dispensed and the lubrication time (Figure 6.a). At a pressure of 2 bars, 19 grams of grease were dispensed with a lubrication time of 13.24 seconds. When the pressure increased to 3 bars, the grease weight decreased to 17 grams with a lubrication time of 9.93 seconds; then, at 4 bars, it decreased further to 14 grams with a lubrication time of 8.96 seconds. These data indicate that as air pressure increases, the lubrication process occurs more rapidly, and the amount of grease retained within the bearing tends to decrease. The decrease in the weight of the grease entering indicates that the grease is forced in more quickly and distributed more evenly throughout the bearing, thereby effectively forming a lubricating film without excessive buildup. Higher air pressure generates a greater thrust force, making it easier for the grease to enter the small gaps in the bearing. This aligns with the views of Lugt (2013) and Lugt (2014) [22], [23], who state that the effectiveness of grease lubrication is more influenced by grease distribution and lubricant film formation than by the amount of grease retained within the bearing.



(c)

Figure 7. Test results for the bearing 30306, pressure vs time (a), bearing weight (b). and grease intake (c)

In Figure 7, for bearing 32206, the test results show that an increase in air pressure in the pneumatic system has a clear effect on the lubrication time and the weight of grease entering the bearing. At 2 bar pressure, the amount of grease entering was 10 grams with a lubrication time of 9.86 seconds. When the pressure was increased to 3 bars, the amount of grease entering decreased to 9 grams with a lubrication time of 7.58 seconds. Furthermore, at 4 bars, the amount of grease entering decreased again to 7 grams with a lubrication time of 6.09 seconds. These results indicate that an increase in air pressure is directly proportional to the efficiency of the lubrication process, as evidenced by progressively shorter lubrication times. Higher air pressure generates a greater thrust force on the grease, allowing it to enter and distribute more quickly into the narrow spaces within the bearing. This aligns with Lugt's (2013) research, which states that external pressure accelerates grease flow and the formation of a lubricating film on rolling bearings. The decrease in the weight of grease retained within the bearing indicates that the grease does not accumulate excessively but is distributed evenly across the bearing element surfaces. This supports the view of Lugt and Velickov (2014), who state that even grease distribution has a greater impact on lubrication effectiveness than the amount of grease retained within the bearing.

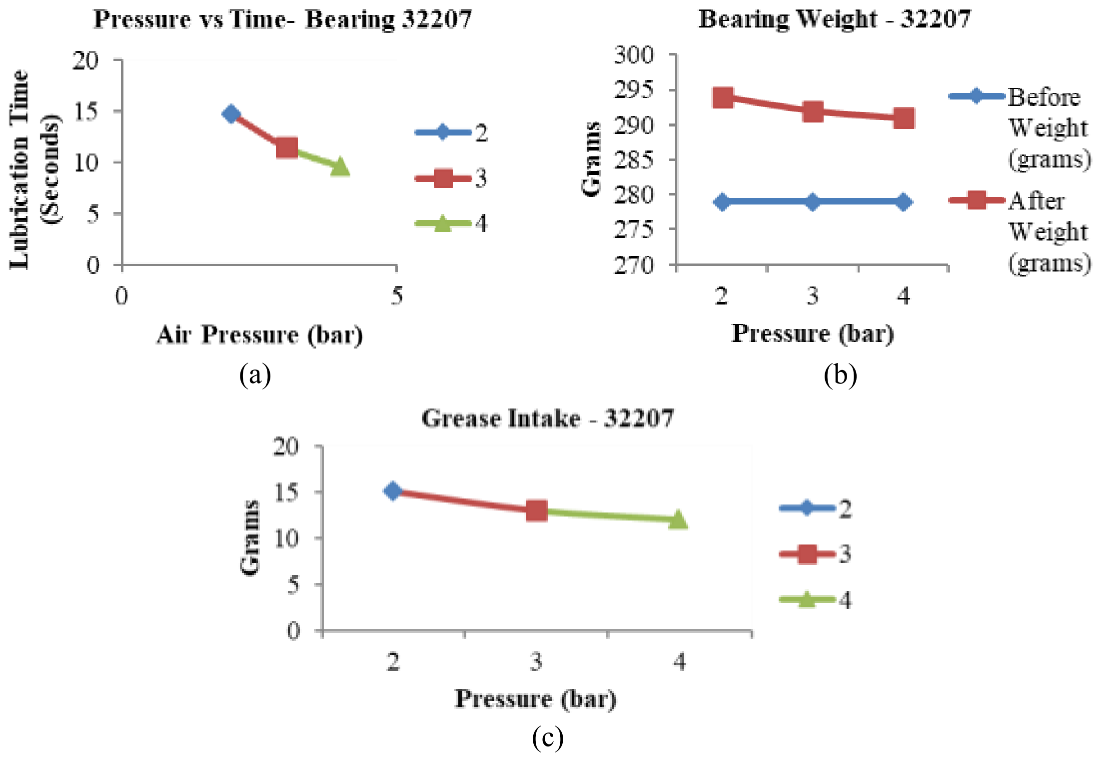
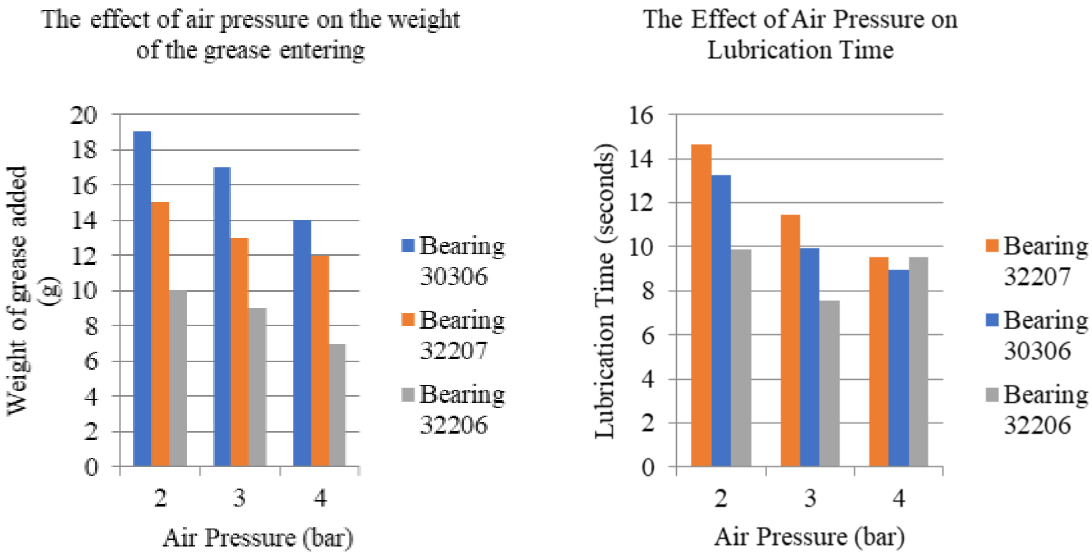


Figure 8. Test results for the bearing 32207, pressure vs time (a), bearing weight (b). and grease intake (c)

As shown in Figure 8, the 32207 bearing has a larger size and lubrication chamber volume than other bearings, so it requires a longer lubrication time, especially at low pressure. At a pressure of 2 bars, 15 grams of grease entered with a lubrication time of 14.65 seconds. When the pressure was increased to 3 bar and 4 bar, the grease weight decreased to 13 grams and 12 grams, while the lubrication time decreased to 11.43 seconds and 9.55 seconds. These results indicate that increased air pressure accelerates grease distribution within the bearing. Higher pressure generates greater thrust, causing the grease to spread more quickly and form a uniform lubricating film without excessive buildup. This aligns with Piet M. Lugt's assertion that external pressure plays a crucial role in accelerating grease distribution and the formation of a lubricating film in bearings with large internal volumes.

4. CONCLUSIONS

A pneumatic-based lubrication aid for forklift wheel bearings was successfully designed and implemented as planned. This system operates effectively and consistently, resulting in a more controlled lubrication process compared to manual methods, as evidenced by relatively stable lubrication times and reduced reliance on operator effort. Based on the comparison of the graphs in Figure 9, variations in air pressure in the pneumatic cylinder have a significant effect on lubrication time and the amount of grease entering the bearing. The longest lubrication time occurred in Bearing 32207 at a pressure of 2 bars, namely 14.65 seconds, while the fastest time occurred in Bearing 32206 at a pressure of 4 bars, namely 6.09 seconds. These results indicate a reduction in lubrication time of 8.56 seconds, or approximately 58.4%, leading to the conclusion that increasing air pressure enhances the efficiency of the lubrication process.



(a) (b)

Figure 9. Graph showing the effect of pressure on the amount of grease dispensed (a); graph showing the effect of air pressure on lubrication time (b)

An air pressure of 3 bars was considered the most optimal condition in this study because it provided faster lubrication times compared to 2 bars, while still delivering enough grease to meet the bearing's lubrication needs. The highest amount of grease was obtained at 2 bar pressure, at 19 grams, whereas at 4 bar pressure it was only 7 grams, resulting in a decrease of approximately 63.2%. Therefore, 3 bar pressure was selected because it provides the best balance between process speed and adequate lubrication. Additionally, bearing size also affects lubrication time and grease requirements. Larger bearings, such as the 32207 bearing, require longer lubrication times and more grease compared to the 32206 bearing. Nevertheless, the pneumatic lubrication system still demonstrated improved efficiency across all tested bearing sizes.

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