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Mekanika: Majalah Ilmiah Mekanika

Analyze The Effect of The Impeller Type on Bearing Rating Life

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Abstract

One of the essential components of a balancing machine is the bearing, which is a crucial component that ensures stability, precision, and efficiency in the balancing process. Although there were high-quality bearings on the market, ongoing research was needed to ensure that balancing machine bearings could supply the specific needs of the industry and continued to improve their reliability and efficiency; the use of bearings specifically designed for balancing applications and of high-quality is necessary to ensure optimal performance and accurate results. This study aims to examine the impact of varying impeller types on balancing machine-bearing life in commercial companies. This research adopts a quantitative causality method, collecting data and samples during the study and then analyzing them using the Analysis of Variance (ANOVA) method. Bearing life is measured using a sum by combining several factors. The results of the research revealed that from ANOVA analysis with an error percentage of 0.05, a significance value of 0.006 was obtained and F = 44.582, F_{table} = 9.55, which means calculated $F > F_{table}$ so it can be concluded that the type of impeller was affected bearing life.

1 Introduction

Rotational machines are equipment that is commonly found and have a vital role in various industrial processes [1]. The manufacturing industry, including commercial company companies in Gresik, East Java, which are engaged in fertilizers and chemicals industries, continues to experience rapid growth due to increasingly complex production requirements and the need for efficiency. One vital aspect of maintaining the performance of these machines is balancing machine maintenance. A hard-bearing balancing machine is a unique tool for balancing complex rotating objects. In this commercial company, the demand for balancing impellers continues to increase yearly, as seen in Figure 1. The graph in Figure 1 shows the demand trend for balancing commercial company fertilizer and chemical impellers in Gresik, East Java, from 2015 to 2023. This data provided an overview of the consistent increase in balancing on impellers, which reflects how Balancing machines are essential in the manufacturing process to increase production efficiency and quality. Increasing demand showed that more and more manufacturing companies require balanced impellers through a balancing process to improve efficiency and product quality. By using balancing machines, companies can achieve a better balance in mechanical components, meaning machines can run more smoothly and with less vibration. This reduces wear and extends engine life. Manufacturing companies can save costs by repairing unbalanced impellers rather than buying new impellers, which are more expensive.

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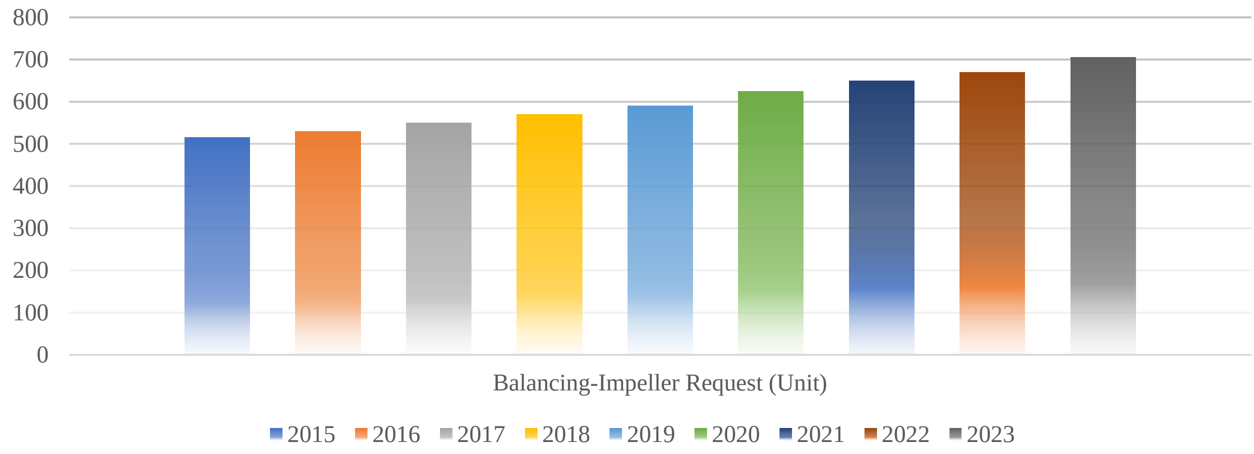

Figure 1. Impeller balancing requested for commercial company fertilizer and chemical in Gresik, East Java

Companies can save on maintenance and repair costs in the long term because the machines operate more efficiently. The increasing demand also reflects advances in balancing machine technology, so higher balancing standards are needed for better results. Therefore, new maintenance and innovations are required to make balancing machines more effective and long-lasting. Balancing machines are essential in ensuring rotating equipment's efficient and safe operation. An imbalance in rotating equipment such as an impeller can have a severe impact on crucial components such as bearings in balancing machines [2].

The impeller was a rotating part of a centrifugal pump. The impeller was transferring the energy needed to transport fluid and accelerate it in a circular direction. This causes the static pressure to increase according to the kinetics because the fluid flow follows a curved path [3]. The shaft rotated the impeller. This part connected the impeller to the motor, allowing the transfer of energy from the motor's rotation to the fluid being pumped [4]. In this research, a variety of impeller types will be tested, including 22C-304A Impeller, 03C-2362 Impeller, 03C-2341 Impeller, 03C-2342 Impeller, 18C-3105 Impeller, and 03C-702B Impeller, to determine the most suitable type of impeller-effect on bearing life on balancing machines commercial company in Gresik, East Java.

Figure 2. Impeller balancing process

Figure 2 shows the balancing process, a technique to ensure that a rotor or shaft rotates without excessive vibration. Initially, the rotor is precisely mounted on the balancing machine, as depicted in the figure. The first step involves rotating the rotor to measure the initial imbalance using sensors on the machine, which detect vibrations and identify the location and magnitude of the imbalance. Based on these data, mass adjustments are made to the rotor at specific positions to achieve balance. Following adjustments, the rotor is rotated again to confirm that the imbalance has been corrected. If the imbalance persists, the adjustment procedure is repeated until the desired result is attained. The rotor is thoroughly inspected in the final stage to verify optimal balance.

The Balancing process is a very effective method for overcoming imbalances in engine rotation. The mass distribution is adjusted evenly along the rotation axis during the balancing process, reducing the imbalance effects. Balancing is an operation that saves money by improving performance, reducing downtime [5]. Balancing machines are also equipped with bearings that aim to regulate the movement of materials or machine components, so they are balanced appropriately. The use of general bearings on this machine plays a vital role in dampening vibrations that arise during the balancing process [6]. A cushion can be defined as the ability of a material to withstand pressure and friction. The importance of analyzing the impact of impeller type on the service life of bearings on balancing machines is by referring to the parts or components of the machine. This method can be used to evaluate whether the tool or component will last for a long time, especially the bearing.

According to Zhang et al. [7], because of their high load-bearing capacity, bearings have been widely applied to many rotating machines in modern industries, such as rail transportation, wind turbines, and aviation equipment. Bearings often operate in harsh working environments and experience varying weight loads, making them susceptible to errors. Severe bearing damage can lead to unpredictable accidents if not identified in time. As a result, condition monitoring and bearing fault diagnosis are critical in maintaining the safety and reliability of mechanical systems.

Werner et al. [8] presents the results of an investigation into the wear and service life of rolling products with solid lubricants in bearings. Regarding wear, it can be seen that the bearing rings tend to increase in mass during service life, while the mass of the balls and cages tends to decrease. Regarding the surface condition of the elements, the surfaces of the bearing rings and balls are checked and determined based on the mass of the elements present on these surfaces. This research focuses on the achieved service life, torque curve, wear development, and surface analysis. The results showed that caged MoS_2 resulted in a longer service life. However, Ag-coated balls did not positively affect service life and even appeared to reduce it when combined with MoS_2.

Unaijah and Darwis [9] state that monitoring its condition is very important to prevent damage and ensure the smooth operation of the machine. One method used to analyze machine life is analysis using the Weibull distribution. This method helps estimate reliability, ease of maintenance, and predict damage to bearings. Based on the research results, the Weibull distribution effectively analyzes failure time data using the least squares estimation method and the maximum likelihood method. However, in this context, the least squares method is more accurate than the maximum likelihood method.

This study also analyzed the service life of bearings on balancing machines in manufacturing plants or similar environments. Implementing these suggestions will increase operational efficiency, reduce production downtime, and extend equipment service life. From the abovementioned context, the problem formulated is the variation in impeller type with load and rotational speed on the balancing machine and its effect on the bearings. To limit the scope of discussion, the problem boundaries are set, i.e., this research was conducted at a manufacturing company in Gresik, East Java. Various types of impellers that will be evaluated include 22C-304A Impeller, 03C-2362 Impeller, 03C-2341 Impeller, 03C-2342 Impeller, 18C-3105 Impeller, and 03C-702B Impeller from a commercial company in Gresik, East Java. The focus of the research is limited to calculating the life of balancing machine bearings using FAG 3206 Angular Contact Ball Bearings. The purpose of this research is to evaluate the impact of variations in impeller type on bearing life on balancing machines for fertilizer and chemical companies in Gresik, East Java, to examine how effective the bearing life of balancing machines is in response to differences in impeller type, and also to provide solutions that can be used to overcome bearing damage on the balancing machine.

2 Experimental Methods

The research approach used in this research is a quantitative causality data collection method, namely a research approach that uses number or quantity-based data collection and analysis methods. This approach aims to measure, analyze, and compile the relationship between the variables studied so that the results obtained are the age of the bearings on the balancing machine and the influence of the impeller type in the commercial company fertilizer and chemicals in Gresik, East Java.

The variables used in this research consist of independent variables and fixed variables, which are explained below:

1. Independent variable
   Independent variables were variables that influenced other variables in this research. The independent variable is a single suction closed impeller with various types, including 22C-304A impeller, 03C-2362 Impeller, 03C-2341 Impeller, 03C-2342 Impeller, 18C-3105 Impeller, and 03C-702B Impeller from a commercial company in Gresik, East Java.

2. Dependent variable
   The dependent variable was a factor that was observed and measured to assess the impact of the Independent variable. This research's dependent variable was the bearing's lifetime on the balancing machine.

3. Control variable
   Control variables were other variables that were observed or measured to ensure that the results were not influenced by other factors, which, in this case, was a single suction closed impeller.

Table 1. Impeller type data

No	Impeller Type	Rotor Weight (kg)	Balancing Test Speed (rpm)
1	Impeller 22C-304A	330	486
2	Impeller 03C-2362	160	298
3	Impeller 03C-2341	260	364
4	Impeller 03C-2342	340	526
5	Impeller 18C-3105	250	338
6	Impeller 03C-702B	190	309

This research adopts a causal-quantitative method, which correlates one variable to another with a cause-and-effect correlation by collecting data and samples during the study and then analyzing the results descriptively. The research objectives prepare the analysis plan. The analysis process is conducted in several stages, from analyzing the impeller type to analyzing bearings on balancing machines, as presented in Table 1, which displays data from various types of impellers that will be studied. To clarify the steps of this research, these stages are divided into several parts, including:

1. Observations are conducted on the impeller balancing machine of a commercial company in Gresik, East Java, to investigate the effect of the type of impeller being balanced on bearing life.
2. Identify the impeller type and bearing used in the balancing machine.
3. After making observations and knowing the specifications of the research object, data analysis is conducted using statistical calculations.

4. The analysis results reveal whether variations in impeller type affect the bearings' life of the balancing machine.

2.1 Balancing machine Hofmann HL-28

A balancing machine is a measuring tool used to balance the rotor in rotating machines, such as electric motors, turbines, disc brakes, disc drives, propellers, screws, impellers, and pumps [10]. A balancing machine measures the size and angle of the imbalance so that it can be corrected by adding, removing, or moving mass [11]. Therefore, this machine is very suitable for production machines with low and medium capacity and also for repair workshops.

Figure 3. Balancing machine

Figure 3 shows the balancing machine hard bearing brand Hofmann model number HL-28 from the commercial company in Gresik, East Java. This tool is used for high-precision rotor balancing. This machine operates with a voltage specification of 380 volts and a current of 63 amperes, accompanied by a control voltage of 220 volts and a 100 amperes fuse on the supply line. It can function at balancing speeds ranging from 100 to 1500 rpm, depending on the rotor type and balancing requirements. The HL-28 model accommodates rotors weighing up to 100,000 kg and a maximum diameter of 1,500 mm. These machines facilitate balancing in one or two planes with a high degree of precision, often achieving unbalance reduction ratios exceeding 95% [12].

Figure 4. Planes 1 and 2 on the balancing machine

Figure 5. Vibration sensor

Figure 6. Balancing machine monitor

This tool has sensors and software to calculate imbalances and instruct the operator on essential actions [13]. Figure 4 shows the plane or support pole for the object to be balanced; there are two planes. Therefore, this machine is also called two-plane balancing. Figure 5 shows sensors on a balancing machine that detect vibration, movement, speed, or imbalance in the equipment to be balanced. The sensor is located in Planes 1 and 2 because it measures the parameters needed to determine the level of balance. Figure 6 is a monitor on a balancing machine. The monitor is used to input data regarding objects such as rotor weight and impeller speed test balancing that will be balanced, and also for storing balancing data that is done. Hard-bearing balancing machines can balance complex objects more effectively, reducing vibration and extending bearing life. A hard-bearing balancing machine is permanently calibrated, resulting in faster setup and better performance with a larger rotor, high driving power, and high wind loads [11]. This type of machine offers greater flexibility and can accommodate components with significantly varying loads, as it measures centrifugal effects and requires only a single calibration. Balancing is a critical aspect in the design and operation of various machines utilizing rotating shafts. Generally, the balancing process is performed after the final stage of system assembly. Nevertheless, in specific systems, such as impellers, screws, and other rotating equipment, balancing is conducted immediately following repairs, rejuvenation, and maintenance procedures.

2.2 Impeller

Centrifugal pumps are essential units in the process industry that generate pressure heads by rotating their impeller, which is mounted on a bearings-supported shaft. The impeller, the principal component of a centrifugal pump, rotates within the casing, imparting energy to the fluid. The shaft and bearings support the impeller, facilitating its rotation within the casing. Seals are employed on the shafts to prevent fluid leaks. Impellers are typically constructed from materials such as iron, steel, bronze, brass, aluminum, or plastic, transferring energy from the motor that drives the pump to the fluid by accelerating it outward from the center of rotation [14].

Figure 7. Single – suction closed type impeller

Figure 7 is a single-suction closed-type impeller. The impeller is actuated by a motor linked to the impeller shaft, while a housing delineates the motor enclosure, facilitating the rotation of the shaft within. Within this setup, the rotating shaft serves as a component for discharge, with one end interfacing with the impeller and the other providing an aperture for the initial end of the discharge passage [15]. Impeller types hinge upon variations in blade design and suction mechanisms. These types encompass three primary impeller types: open, semi-open, and closed, contingent upon the specific design characteristics of the impeller. Furthermore, concerning suction attributes, impellers are categorized as either single or double-suction configurations [16].

Figure 8. Single – suction closed type impeller

This research will compare the effect of a single-suction closed-type impeller as in Figure 8. Within a closed impeller configuration, the blades are enclosed by two walls, forming a single unit at both the front and rear, thereby optimizing power transfer to the pump. Conversely, "single-suction" refers to a pump where fluid ingress occurs from one side of the impeller, whether the front, side, or rear, facilitating a straightforward construction and thus widespread applicability. Due to differential pressure on opposing sides of the impeller, an axial force is generated towards the suction side, necessitating the inclusion of an axial bearing within the construction.

2.3 Types of bearings

Rolling element bearings, also called anti-friction bearings, represent the predominant choice for supporting centrifugal pumps. Single-row and double-row ball bearings exhibit proficiency in sustaining radial and axial loads. Conversely, roller bearings excel in enduring high radial loads but exhibit limited capacity to withstand axial loads [17]. A bearing constitutes a mechanical component constraining the relative motion between two or more machine elements, ensuring consistent movement along specified trajectories. Bearings prevent incessant rotation of a shaft about its axis or maintain linearly moving components aligned with their intended path. Engineered for simplicity and robustness, bearings are typically situated in concealed locations, rendering them challenging to access during maintenance procedures [18]. Typically, a bearing comprises two rings featuring lines or tracks (raceways), namely an outer ring and an inner ring, facilitating the fixed rotation of the bearing elements. The longevity and efficacy of bearings are contingent upon maintaining a clean operational milieu and appropriate lubrication practices. Typically, environmental cleanliness is upheld through effective sealing mechanisms encircling the shaft, thereby mitigating the ingress of contaminants such as fluids and particulate matter into the bearing housing [17].

Figure 9. Bearings of balancing machine

Bearings in this balancing machine use an angular contact bearing double row, as in Figure 9, which is also identified as an anti-friction bearing. Angular contact bearings are frequently employed in applications necessitating the capability to endure substantial thrust loads. For instance, the FAG 3206 type, constructed from American Iron and Steel Institute (AISI) 4340 roller-bearing material exhibiting a hardness of up to 60 HRC, is commonly utilized. However, friction between bearing constituents, including outer bearings, outer rings, balls or rollers, and inner rings, may ensue due to imbalanced loads and high rotational speeds, leading to diminished bearing longevity.

Table 2. Specification bearing FAG 3206 – BD – XL

No	Type Bearing	*d* (mm)	*D* (mm)	*B* (mm)	C_r (N)
1	3206-BD-XL	30	62	23.8	31,000

Table 2 presents the bearing specifications of the Hofmann HL-28 balancing machine, which uses FAG 3206-BD-XL Double Row Angular Contact Ball Bearings. These bearings are designed to handle radial and axial loads and are often used in machinery, pumps, etc. Bearing type 3206-BD-XL has specifications: inner diameter 30 mm, outer diameter 62 mm, and width 23.8 mm. Additionally, its dynamic load capacity is 31,000 N.

Table 3. The average value of the friction coefficient on the bearing

No	Type Bearing	Start		During rotation	
		Radial	Axial	Radial	Axial
1	Ball bearing	0.0025	0.0060	0.0015	0.0040
2	Spherical roller bearing	0.0030	0.1200	0.0018	0.0080
3	Cylindrical roller bearing	0.0020	---	0.0011	---

Despite being commonly referred to as anti-friction bearings, Rolling Bearings still experience friction among their components, specifically the outer ring, ball or roller, and inner ring, due to the applied load and rotational movement. The friction coefficient (*F*) is detailed in Table 3 and is contingent upon the bearing type, operational conditions, and specific friction characteristics. This data stems from extensive research conducted over numerous years [19].

2.4 Prediction of bearing life

Bearing life calculations serve to ascertain the dependent variable, namely the lifespan of bearings installed on the balancing machine, and also to discern the impeller type exerting the most significant impact on said bearing life. Assuming uniform rotational conditions, the projected bearing longevity, quantified in operational hours, can be computed utilizing the subsequent Equation 1.

$$L_{10h} = \left(\frac{c}{p}\right)^{b} \times \frac{10^6}{60.n} \quad (1)$$

where:

L_{10h} = Bearing life (working hours)

c = Dynamic loads are obtained from an inner-diameter bearing that is 30 mm with dimensions series (*angular contact ball bearing*), so that will be obtained value 31,000 N

n = Axis rotation (rpm)

p = Radial loads (N)

b = Constanta that depends on the type of load (b = 3 for ball bearing)

2.5 Research flow chart

The flowchart in Figure 10 delineates the sequential phases of the research methodology. Initiation commences with the field study phase, involving investigations conducted at commercial enterprises in Gresik, East Java. Subsequently, the researcher articulates the problem during the problem formulation stage. Following problem formulation, a comprehensive literature review explores prior scholarly investigations pertinent to the identified research issue. The researcher delineates the goals in the subsequent phase termed 'objectives.' Subsequently, the data collection phase ensues, during which the researcher acquires requisite data for the investigation. The data comprises primary data from its origin, encompassing interviews, machine operator feedback, and observational records of objects, events, or test outcomes, alongside secondary data derived from pre-existing sources such as books, notes, archival evidence, or scholarly articles.

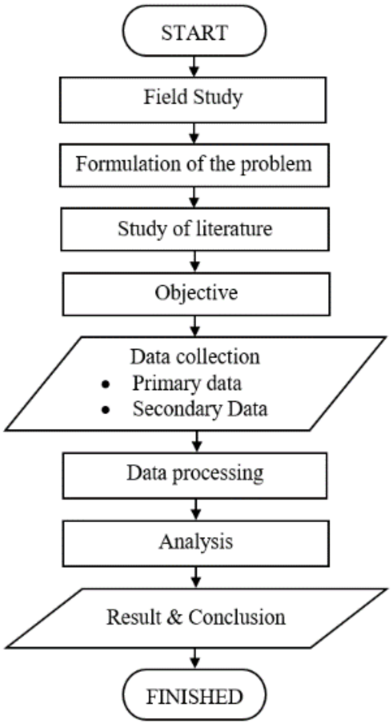

Figure 10. Research flowchart

Upon completion of data collection, the researcher proceeds to the data processing phase, where collected data undergoes preparation for analysis. Data about variables such as bearing type and impeller type are subjected to descriptive statistical methods. Subsequently, in the analysis phase, the processed data is scrutinized to derive meaningful insights regarding the influence of impeller type on bearing longevity in balancing machines. Based on the findings, the researcher compiles the research outcomes and formulates conclusions during the result and conclusion phase. The research process culminates at the "FINISHED" stage, indicating the completion of all research stages. Additionally, recommendations are proposed for the practical application of the research findings.

3 Results and Discussion

Calculating the bearing lifespan on a balancing apparatus verifies the dependent variable's value. In this investigation, the dataset originates from "Fischer's Automatische Gusstahlkugelfabrik" (FAG) bearing catalog, supplemented by impeller specifications, including weight and testing velocity during the balancing process. The balancing apparatus features four primary bearings, with two on each support plane and two on each supporting bearings serving as stabilizers for the balanced equipment. In this research, we only calculated the life of the four main bearings that work the most. The following are the results of calculating bearing life on balancing machines with various impeller types, including 22C-304A Impeller, 03C-2362 Impeller, 03C-2341 Impeller, 03C-2342 Impeller, 18C-3105 Impeller, and 03C-702B Impeller commercial company in Gresik, East Java. Calculation of the life of the balancing machine bearings uses Equation 1. This is conducted to obtain values and determine the bearings' life on the balancing machine's performance. The results of calculating the impact of the impeller on bearing life on a balancing machine are summarized in Table 4.

Table 4. The result of the bearing life calculation to a variety of types of impeller

No	Type Impeller	Rotor Weight (kg)	Balancing Test Speed (rpm)	Bearing life (Working hours)
1	Impeller 03C-2362	160	298	431,318.79
2	Impeller 03C-702B	190	309	248,401.83
3	Impeller 18C-3105	250	338	99,686.39
4	Impeller 03C-2341	260	364	82,291.20
5	Impeller 22C-304A	330	486	46,226.79
6	Impeller 03C-2342	340	526	41,087.93

Data in Table 4 presents the results of calculating bearing life on a balancing machine. From these results, it can be concluded that the Impeller 03C-2342, which weighs 340 kg with a balancing test speed of 526 rpm, has the most significant impact with a bearing life of 41.087.93 working hours. The impeller with the most negligible impact on bearing life on balancing machines is Impeller 03C-2362, with a rotor weight of 160 kg, balancing test speed of 298 rpm, and bearing life reaching 431,318.79 working hours.

Table 5. Statistical test results for bearing life on various impeller types using ANOVA

ANOVA[a]					
Model	**Sum of Squares**	***df***	**Mean Square**	***F***	**Sig.**
Regression	1143229512807845.800	2	571614756403922.900	44582	.006[b]
Residual	38465116431586.930	3	12821705477195.643		
Total	1181694629239432.800	5			

a. Dependent Variable: Bearing lifespan; b. Predictors: (Constant), Balancing test speed, rotor weight

Table 5 shows the results of ANOVA analysis with an error percentage of 0.05, obtained a significance value of 0.006, and calculated $F > F_{table,}$ thus answering the hypothesis that the impeller type confirms the existence of a significant relationship between the predictor variables, namely the impeller type influences the life of the bearings on balancing machines $F = 44.582$, $F_{table} = 9.55$. The mean square for the regression is 571614756403922.900, while the mean square for the residual is 12821705477195.643. mean square is calculated by dividing the sum of squares by the corresponding degrees of freedom.

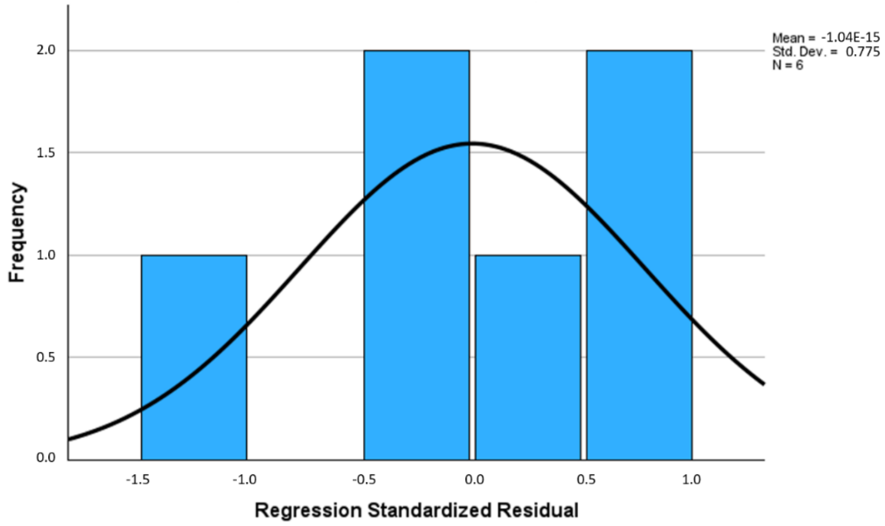

Figure 11. Histogram graph of the correlation between bearing lifespan and working hour

Figure 11 is a histogram graph illustrating the distribution of standardized regression residuals for the dependent variable, explicitly bearing life measured in working hours. The horizontal axis represents the standardized regression residuals, defined as the discrepancy between the model-predicted and normalized actual values. The vertical axis indicates the frequency or count of occurrences of these standardized residuals within each interval. The blue bars in the histogram depict the frequencies of the standardized residuals. The black curve superimposed on the histogram bars represents the expected normal distribution of the residuals, assuming the regression model accurately fits the data. A distribution of residuals that aligns with this curve suggests that the residuals are normally distributed, which is a crucial assumption in linear regression analysis. The mean of the residuals is 1.04×10^{-15} with a standard deviation of 0.775. The sample size for this analysis is 6 (N=6).

In this case, the independent variable is the impeller type, including balancing test speed and rotor weight, with the dependent variable being bearing lifespan. Thus, it can be concluded that the impeller type significantly influences bearing lifespan. This analysis provides a strong basis for concluding that the balancing test speed, rotor weight, and the heavier the impeller speed, the shorter the bearing life of the balancing machine.

Previous research conducted by Mubarok et al. [20], it is introduced the factors that cause damage to the bearings of the Nordenmatic 702 Filling Up Tube machine, namely the machine, man, and menthol factors. These factors significantly impact bearing damage and can disrupt the machine production process. The research conducted by Rachman et al. [21] demonstrates that bearings lacking lubrication exhibit elevated vibration characteristic values, leading to accelerated bearing deterioration within a brief timeframe. These findings substantiate that the absence of lubrication is directly linked to swift bearing degradation. In contrast, research conducted by Lubis et al. [22] notes that the type of bearing or material used in bearings significantly influences the bearings' lifespan. The research findings indicate that bearings made of structural steel exhibit superior durability and strength compared to aluminum alloys.

4 Conclusions

The rotor's weight and the balancing test's speed on each impeller type greatly influence the life of the balancing machine bearing. The heavier and faster the impeller rotates, the shorter the bearing life. Based on the analysis data, the influence of impeller type on the life of balancing machine bearings. Factors influencing the reliability and service life of bearings include rotational speed, unbalanced objects, and the load received by the bearing. The impeller with the most significant impact on bearing life on balancing machines is the 03C-2342 Impeller, with a service life of 41,087.93 working hours. On the other hand, the 03C-2362 Impeller has the most minor influence on bearing life on balancing machines, with only 431,318.79 working hours. Rotor weight or the weight of the impeller and the balancing test speed. Therefore, it was recommended that routine checks be carried out and regular lubricants be provided so that bearing maintenance can be carried out efficiently, downtime can be reduced, and the service life of the bearing can be extended. These steps are expected to reduce the risk of damage to balancing machine bearings, thereby reducing operational downtime and extending the service life of bearings. Additional research is needed to analyze bearing life using various other types of equipment to determine the right time to replace bearings on balancing machines to achieve optimal balancing results.

References

1. R. Mihalache, I. S. Vintila, M. Deaconu, M. Sima, I. Malael, A. Tudorache, and D. Mihai, “Novel carbon fibre composite centrifugal impeller design, numerical analysis, manufacturing and experimental evaluations,” *Polym.*, vol. 13, no. 19, article no. 3432, 2021.
2. J. Vance, F. Zeidan, and B. Murphy, *Machinery Vibration and Rotordynamics*, New Jersey: John Wiley & Sons, 2010.
3. J. F. Gülich, *Centrifugal Pumps*. New York: Springer International Publishing, 2019.
4. A. Clark, *Impeller Pumps Reference Guide*. British Columbia: Specific Speed Enterprises Ltd, 2018.
5. D. Norfield, *Practical Balancing of Rotating Machinery*, Oxford: Elsevier Science, 2005.
6. R. K. Mobley, *Vibration Fundamentals*, Oxford: Newnes, 1999.
7. Z. Zhang, W. Huang, Y. Liao, Z. Song, J. Shi, X. Jiang, C. Shen, and Z. Zhu, “Bearing fault diagnosis via generalized logarithm sparse regularization,” *Mech. Syst. Signal Process.*, vol. 167, article no. 108576, 2022.
8. M. Werner, S. Emrich, O. Koch, B. Sauer, and M. Kopnarski, “Long-Term Investigations of Different Bearing Configurations at Solid-Lubricated Rolling Bearings,” *Tribol. Trans.*, vol. 67, no. 3, pp. 401-410, 2024.
9. U. Unaijah and S. Darwis, “Prediksi Sisa Umur Bearing Menggunakan Distribusi Weibull,” *Jurnal Riset Statistika*, vol. 2, no. 1, pp. 75-84, 2022. (*in Indonesian*).
10. R. K. Mobley, *Maintenance Fundamentals*, Oxford: Elsevier Science, 2004.
11. D. Norfield, *Practical Balancing of Rotating Machinery*, Oxford: Elsevier Science, 2005.
12. Hofmann, *Horizontal, hard-balancing balancing machines*, Hofmann, Available in https://www.hofmann-global.com/en/products/universal-balancing-machines/horizontal.html (Accessed in January 10, 2024).
13. A. Kumar, C. P. Gandhi, Y. Zhou, R. Kumar, and J. Xiang, “Variational mode decomposition based symmetric single valued neutrosophic cross-entropy measure for the identification of bearing defects in a centrifugal pump,” *Appl. Acoust.*, vol. 165, article no. 107294, 2020.
14. G. Vashishtha and R. Kumar, “Centrifugal pump impeller defect identification by the improved adaptive variational mode decomposition through vibration signals,” *Eng. Res. Express*, vol. 3, no. 3, article no. 035041, 2021.
15. G. D. Haryadi, I. Haryanto, I. M. W. Ekaputra, R. T. Dewa, and D. Setyawan, “Analisa Struktur Dan Performa Impeller Pompa Sentrifugal Dengan Menggunakan Computational Fluid Dynamic dan Finite Element Method,” *Jurnal Rekayasa Mesin*, vol. 13, no. 3, pp. 773-786, 2022. (*in Indonesian*).
16. B. Kim, M. H. Siddique, A. Samad, G. Hu, and D. E. Lee, “Optimization of Centrifugal Pump Impeller for Pumping Viscous Fluids Using Direct Design Optimization Technique,” *Machines*, vol. 10, no. 9, article no. 774, 2022.
17. Suharto, *Pompa Sentrifugal*, 1st ed. Jakarta: Ray Press, 2016.
18. S. Buchaiah and P. Shakya, “Bearing fault diagnosis and prognosis using data fusion based feature extraction and feature selection,” *Measurement*, vol. 188, article no. 110506, 2022.
19. A. D. Deutschman, W. J. Michels, and C. E. Wilson, *Machine Design; Theory and Practice*, London: Macmillan, 1975.

20. M. R. Mubarok, A. Apriana, F. Mulyana, "Studi Kasus Kerusakan Bearing Mesin Filling Up Tube Nordenmatic 702 Di PT. XYZ," *Prosiding A Seminar Nasional Teknik Mesin*, vol. 13, no. 1, pp. 82-89, 2023. (*in Indonesian*).
21. A. Rachman, B. Hartono, and D. Yuliaji, "Analisa Getaran Pada Bearing Berbasis Kerusakan Bearing," *Aplikasi Mekanika dan Energi*, vol. 4, no. 1, pp. 15-22, 2018. (*in Indonesian*).
22. F. Lubis, R. Pane, S. Lubis, M. A. Siregar, and B. S. Kusuma, "Analisa Kekuatan Bearing Pada Prototype Belt Conveyor," *Jurnal MESIL (Mesin Elektro Sipil)*, vol. 2, no. 2, pp. 51-57, 2021. (*in Indonesian*).