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Precision Maintenance Strategies: Understanding and Addressing Coolant Oil Contamination's Influence on Grinding Machine Bearing Integrity

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Abstract *:* One of the main reasons for machining breakdowns in a given industry is bearing failure. Rolling bearings are made up of bearing rings, rolling components, and cages for the rolling components' support. The term 'bearing life' refers to the total amount of revolutions (or periods) a bearing can withstand before failing. Cracks, inadequate lubrication and greasing, and insufficient bearing loading on the shaft are common failure modes. The work presented here comprises several rolling bearing damage diagnosis methods and failure scenarios. Fluid contamination is considered one of the main reasons for failure in hydraulic systems. That said, there are hydraulic systems that intentionally use water as the design fluid and there is oil in water systems for various uses. The majority use specific hydraulic fluid that is less susceptible to temperature effects and provides lubrication properties. Transmission fluid can be classified as either a hydraulic fluid or a lubricant, depending on the transmission type. Moisture is a known contaminant in a wide variety of applications, but moisture in industrial oil can be particularly damaging. In addition to impacting oil performance, water degrades additives and film strength, thus presenting the opportunity for mechanical wear and corrosion. Standard equipment features such as breathers are designed to evaporate moisture from the oil. When preventative measures fail, the water content in oil can reach.

Keywords: Inner and outer ring raceway, faults, Diagnosis, Coolant filter machines, Fault detection, Condition monitoring

1. Introduction

Understanding how much water it takes to cause problems is the key to service and prevention. Much like the relative humidity in air, oils can hold more water molecules are the temperature increases. This is directly related to the energy of the individual molecules, which allows them to move more freely and independently. This can pose specific challenges for oil moisture management, as operating temperatures are always higher than resting temperatures. During operation, water contamination can be absorbed without separation, only to separate and form free water when the machines stop and temperatures decrease. The damage spread to a cylindrical roller bearing's inner ring raceway was scratched by a hard contaminant after being over-rolled. Just behind the indentation, a surface-initiated fatigue that ultimately contributed to a spill occurred. Spilling gradually increased in harshness over time [1-4]. If the machine had not been stopped in time, additional damage to its components might've occurred. It is no longer conceivable to locate the original indentation. Industrial used oil, generated as a by-product of machinery and equipment operations, poses significant challenges to environmental sustainability if not adequately managed. The presence of contaminants, degradation products, and altered chemical properties reduce the reusability of used oil, increasing the need for proper treatment [5-9]. This study aims to compare different processes to enhance the quality of used oil, thereby enabling its effective reuse in industrial applications. By analyzing the performance of various treatment techniques, the study aims to provide insights into the most effective approaches for improving the reusable quality of industrial used oil.

2. Literature Survey

Imagine a rolling-element bearing as a kind of wheel that helps things move smoothly. It's made up of two rings, almost like tracks, and inside these rings are small balls or rollers. When something needs to move, these balls or rollers rotate, reducing friction and making the movement much easier. They're like tiny helpers ensuring things glide along smoothly without causing too much wear and tear. The majority of the time, bearing failures arise from the bearing's substance wearing out [10-13]. A small crack that is present inside the surfaces of the raceway and rolling components is where fatigue failure starts to occur under normal operating circumstances. The cracks eventually propagate and expand as a result of the repeated collisions between the bearing's parts and the faulty surfaces, increasing vibrations and noise levels [14-17]. The detachment of some tiny cells results from the damaged area being repeatedly agitated. Bits of the substance, which result in a flaking or spilling occurrence. Each time a moving component runs over the fault, the vibration signal's pattern consists of several oscillations that recur. The location of the fault determines the impact's repetition frequency. The rolling element, the outer race, or the inner race may all be at fault. A cage that prevents contact between the balls and maintains a constant distance between them fixes and holds the balls together [23-25].

2.1. Magnetic Separators

These systems can work in continuous and non-continuous modes and are restricted to Ferro-magnetic contamination in comparison to other methods of filtering. A non-contiguous technique can involve a permanent magnet dissolved in the fluid that is cleaned while the machine is not in use. Band or magnetic drum separators are more efficient than continuous systems. In these, the drum or band scrapers continuously remove the imprisoned dirt particles. The most common use of double drum-type magnetic separators is for their high-purity functioning. In a machine of the Double Drum kind, the material will go through the magnet twice [26-28]. To discriminate iron pollution from minerals, chemicals, refractory, and many other items, it is primarily employed. High-power magnetic separators that are double drum type at a material outlet; there is a permanent magnetic plate available. Isotropic permanent magnets, which have the highest coactivity and pervasive magnetic strength, are employed nowadays. To prevent dusting and pollution, machines are available with vibrating material inlet hoppers that are entirely enclosed designs. According to need, online fitting design is also available.

2.2. Data Sample and Collection

In this study, data from oil analysis conducted over five years at an unnamed power plant were utilized. The dataset comprises over 1,000 instances and involves the examination of twenty different variables extracted from oil samples. These samples were rigorously analyzed in a globally recognized laboratory, and the study reports the findings derived from this comprehensive analysis.

2.3. Data Preparation

The data gathered needed to be cleaned to ensure the authenticity of any missing data, some outliers had to be accurately reviewed and the various results must be merged into a single, capable analysis dataset. Because the variables were measured on different scales, the data was accepted as normal.

3. Methodology

According to studies on fault diagnosis, bearing failures account for around 40% of induction machine failures. The bearing-related problems do not result in an abrupt breakdown; rather, they develop over time until they result in a major machine failure. Unfortunately, these failures cause both downtime and expensive repairs Bearing failures can be caused by a variety of elements, such as material deterioration, overheating, harsh circumstances, insufficient storage, contamination, corrosion, incorrect handling and installation, etc. However, the main cause of their failure is a lack of lubrication, which is easily preventable with the appropriate maintenance plan. Specialized tools are used to check the state, and vibration-based surveillance methods are often used to diagnose the sensors. Additionally, they require access to the machine that is being tested, which is not always accessible. In contrast to the approaches mentioned above, current monitoring just needs straightforward, inexpensive current sensors, which are typically already on hand. Numerous flaws, such as broken rotor bars, shorted windings, air-gap eccentricity, bearing faults, load faults, etc., can be found using the current monitoring-based methodologies. The methods and procedures utilized for data collecting, data description, and statistical approach for data analysis are discussed in this part. The analysis of ball bearing damages is given in Table 1.

Table 1. Analysis of ball bearing damage

Symptoms	Source of Table	Examples
Coolant oil contamination	• Damaged rings or rolling elements • Oil Contamination • Excessive clearance	Due to oil filtration not working properly, the filter life expired.
Reduced working accuracy	• Wear due to contaminants or insufficient lubrication. • Damaged rings or rolling elements • Changed adjustments (clearance or preload)	Coolant did not flow in the grinding wheel process for the bearing outer and inner ring process.
Uncommon running noise: Grinding wheel or fixture alignment	• Insufficient operating clearance	Oil coolant viscosity is very high or very low, it will affect the bearing process (Ex., surface roughness, chattering, dent marks)
Coolant oil filtration problems	• Excessive operating clearance Damaged running surfaces	

3.1. Research Methodology

This study's objectives are to identify probable ring failures during bearing production, assess their causes, and provide fixes. It is an effort to assess potential failure that might occur in the various bearing manufacturing industries. An overview of probable failure by many authors is provided in the first section. The purpose of the next section's literature research was to identify potential causes and remedies for each failure. The cases being thought of are take-up from established journals and publications. However, only 7 of the failures that were most likely to have occurred were taken into consideration due to the paucity of published study literature and the difficulty of the author in readily disclosing the details of the issue. The analysis of each example is then presented in the order listed below.

- Review of relevant literature on failures.
- Possibilities for failures when grinding.
- The issue, its cause, and its resolution.

3.2. Problem Statement and Methodology

The traditional and current method for oil monitoring has been through sampling and laboratory analysis. No other method will provide a more complete set of tests to determine the total quality and chemical makeup of oil. The analysis is most commonly performed by Karl Fisher titrations, where reagent chemicals are added to produce colorimetric reactions. This can be done with small volumes and for a large number of different chemicals in the sample. There are limitations and challenges associated with this method, especially when it comes to measuring water content. Collecting and analyzing samples can be a lengthy process, and collection methods can potentially expose samples to the atmosphere or other sources of contamination. And, the water content is only expressed in terms of total PPM. This does not account for the form of the water, the oil's temperature, or the saturation point, which doesn't allow for real-time control of processes making it challenging to anticipate some of the water-induced failures. As an alternative, online water activity measurement supports dependable equipment performance at all hours. This technique not only lowers the possibility of human error, but also saves money on labor, machinery, and chemicals. The most recent in-line water activity measuring technique makes use of an absorption-based capacitive-type sensor.

Applications involving sizable hydrodynamic or oil systems, such as paper machine lubrication, turbines, and oil reclamation systems, make good candidates for this in-line technology. Control systems can be connected to instruments to generate alarms and the defects of rolling bearings are dealt with in great detail in articles on the fault diagnosis of induction equipment. Although vibration-based condition monitoring techniques are typically used for bearing diagnosis, stator current analysis is frequently utilized in publications because of its benefits. The techniques used for stator current analysis separate the signal and evaluate it using several approaches, including Fourier statistical analysis, wavelets, neural networks, etc. Two different forms of bearing faults a hole drilled into the outer raceway and an indentation made in the inner and outer surfaces are analysed by the authors. Analysis of vibration and current is used for both types of faults. For both issues, the precise characteristic fault frequencies are highlighted.

The inspection of the initial defect uncovers two key components: "fess food" and "fess 2fod" within the current spectrum, and "food" and "2fod" in the vibration spectrum. In contrast, the second type of fault exhibits highlighted characteristics: "[fess food]," "[fess 2fod]," and "[fess fid]" in both the vibration and current spectrums. The authors of this study introduce a unique approach in spectrum analysis used to pinpoint bearing failures in induction motors powered by frequency power converters. They highlight a distinctive change in the specific fault frequency components within the current spectrum, identifying the fault as an outer race defect. The investigation into two inner raceway faults, involving drilled holes and spalls, utilizes vibration and current analysis. The results indicate that only the vibration spectrum can effectively display the frequencies associated with these faults, showcasing the differential capabilities of each analysis method. The assembling, dismantling, remounting, and realigning of the test motor, according to the authors, may affect the vibration and current spectra. This does not account for the form of the water, the oil's temperature, or the saturation point, which doesn't allow for real-time control of processes making it challenging to anticipate some of the water-induced failures. As an alternative, online water activity measurement supports dependable equipment performance at all hours. This technique not only lowers the possibility of human error, but also saves money on labor, machinery, and chemicals. The most recent in-line water activity measuring technique makes use of an absorption-based capacitive-type sensor. Applications involving sizable hydrodynamic or oil systems, such as paper machine lubrication, turbines, and oil reclamation systems, make good candidates for this in-line technology. Control systems can be connected to instruments to generate alarms and shut down vulnerable equipment.

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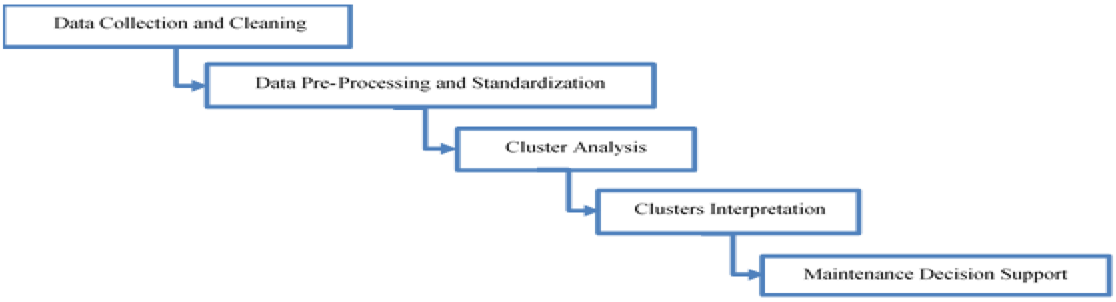

Figure 1. Schematic representation of methodology

The authors examine two types of bearing faults: indentations on the inner and outer surfaces, and a hole in the outer raceway. They use vibration and current analysis to study these defects, identifying the characteristic fault frequencies for each case.

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4. Cluster Analysis – Statistical Analysis

To make each cluster as consistent as feasible regarding the clustering variables—which may differ from those generated from other clusters concerning certain characteristics—a statistical approach known as cluster analysis combines different objects or observations into clusters based on their similarities.

Cluster analysis can be of two main types:

Hierarchical techniques the number of clusters produced by these technologies is lower than anticipated right away. The agglomerative and contentious techniques are the two types of clustering that are available. The variables are first organized into their unique clusters in agglomerative methodologies. Repeatedly merging the two ‘closest’ (most similar) clusters results in an amalgamation of all variables into one cluster.

In the*, end * the optimum amount of clusters is selected from all cluster solutions. When employing the divisive techniques, the process of clustering is repeated in reverse until all topics are in the appropriate groups, having all variables clustered into the same cluster. Aggregative strategies have a greater prevalence than divisive ones because of their usefulness. Non-hierarchical techniques (also known as k-means clustering methods): with such methods, the number of clusters that * required has been predetermined and the 'best' solution is chosen. The heuristic nature of cluster analysis indicates that it is capable of finding clusters in the absence of an ordered set of variables in the data, with many additional limitations.

Clustering frequently creates groups from noise in the data that may have been an outcome of sampling error or sample strategy error when external cross-validation or equivalent procedures are used. It is critical to show that the grouped variables are reliable because of this. The uncertainty of results caused by data sampling error has generally not been investigated in the context of cluster analysis of lubricant data in practice. We wish to determine the degree of vagueness in this study to build clusters with a particular degree of certainty. Through a multistage bootstrap resampling analysis, the probability values (p-values) for each cluster during the hierarchical clustering process are calculated.

A cluster's P-value, which ranges from 0 to 1, represents the length of time to which the cluster is supported by data. Using bootstrap resampling methods, the Pv-cluster R software function estimates the p-values for each cluster. There are two different kinds of p-values: the Bootstrap Probability (BP) value and the Essentially

Unbiased (AU) p-value. The AU p-value can be calculated using multistage bootstrap resampling, which has a lower bias than the BP value generated using conventional bootstrap resampling. Moreover, the utilization of parallel computing presents a valuable opportunity to significantly reduce processing time. In assessing the uncertainty inherent in hierarchical cluster analysis, the PV cluster employs bootstrap analysis within the statistical software. Particularly in phylogenetic analysis, a specialized form of hierarchical clustering utilized to reconstruct the evolutionary history as a dendrogram, the importance of evaluating uncertainty has been long recognized.

Clusters with AU (Approximately Unbiased) p-values exceeding 95% are deemed to have substantial support derived from the data, signifying their reliability. This methodology is particularly advantageous when several variables deviate from a normal distribution, as observed in the data under study. Spearman's correlation coefficient, suitable for non-normally distributed data, is effectively employed in such cases, facilitating a more appropriate analysis.

4.1. Maintenance Decision Support

The author discusses and draws maintenance-related insights from the cluster descriptions and interpretations, highlighting the impacts of fuel dilution and potential causes that, if examined, would minimize the occurrence and impact of the problem. Water-miscible cutting fluid system disinfectants. The complete cleaning and disinfection of the cutting fluid system can have a significant impact on the service life of a water-miscible cutting fluid. Only when systems are appropriately cleansed and disinfected before initial filling can tolerable excellent service life be achieved. High-pressure or steam cleaners can be used to clean cutting fluid tanks and chip conveyors, but it is extraordinarily difficult to mechanically clean pipes and other fluid circuitry. Following any such mechanical cleaning, disinfection is clean and disinfect difficult to-the cutting fluid systems out of reach and inaccessible areas.

Special agents make sure that certain areas receive moisture in these goods. They eliminate bacterial colonies, fungal infestations, and deposits. The built-in emulsifiers move contaminants throughout the system and dissipate floating objects of creamy oil. System cleansers' tiny biocides 'disinfect' the entire system. It's crucial to follow the suggested application time and concentration suggestions when utilizing system cleaners. Always adhere to the manufacturer's recommendations when using the cleaner. The strategy listed below has been successful: Drain the tank and perform a mechanical cleaning of the tank, conveyor, etc. before washing.

4.2. Material

Steel alloy AISI 52100 can be used as a rolling contact-bearing component. In oxidation and acidic conditions, it demonstrates outstanding corrosion resistance, strong wear resistance, low cost, and high compressive strength. The AISI52100 steel's mechanical, chemical, and thermal properties are shown

4.3. Separating Fluid Contamination

These days, customers are given access to a wide choice of devices that can either be permanently placed or used as mobile systems. The image of a typical hand refract meter used to measure fluid concentration is shown in Figure 2 When choosing this type of machinery, it is important to keep in mind that the emulsion can be carried out with any tramp oil plus the initial investment expenses and ongoing maintenance costs. The oil contamination filter is shown in Figure 3. It is recommended that tests be conducted on the system ahead under actual world conditions to prevent unpleasant surprises afterward.

Figure 2. Typical hand refract meter used to measure fluid concentration

Figure 3. Oil contamination filter

The disparity in pressure between the housing of the equipment and the atmosphere outside is one of the primary causes of water penetration. The rate at which the oil absorbs the moisture given into the housing depends on the temperature, soil type, and agitation of the lubricant. Use a closed-system type constant level oiler and a sealing plug-in instead of the vent to reduce the amount of water that enters the system. Some seals need an expansion chamber for the reason that they can't handle the pressure after equalization.

If water or moisture is an acknowledged issue, there are lots of commercially available products to help with its removal. Desiccant-type dryers evaporate moisture and, once maximum absorption has been achieved, incur color change. Another technique used to separate the water from the oil is filtration. A diagram of a closed system oiler with an expansion chamber and a desiccant dryer after the grinding process, removing grinding particles from the coolant oil is shown in Figure 4. This kind of technology would prevent too much water from seeping into the oil when used with sufficient bearing housing seals.

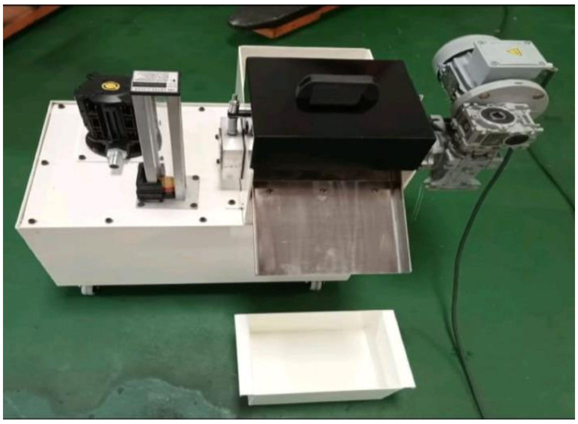

Figure 4. Removing grinding particles from the coolant oil after the grinding process

5. Working Principle and Magnetic System

A repaired permanent magnetic assembly that traverses the width of the drum with a constant, uniform magnetic field that is more effective about half of its navigate constitutes a permanent magnetic drum. The magnetic field passes around the nonmagnetic stainless steel drum shell. Iron particles are drawn to and held to the rotating shell by a powerful magnetic attraction as the material fed evenly from the chute falls over the drum. The nonmagnetic material falls freely from the revolving shell while the iron particles are carried through the stationary magnetic field, but the iron particles are firmly retained until they are carried beyond the separation to the outside of the magnetic field. An analogous electromagnetic drum undoubtedly will have a lower maximum strength than a permanent magnetic drum. The employed permanent magnets are everlasting magnets, whose strength remains intact under typical use and which can be used for a very long time after installation. Based on the relative magnetic field strength used in achieving separation, the three main categories of magnetic separation equipment for the processing of minerals are low, medium, and high intensity. Low-Intensity Magnetic Separators (LIMS) are frequently employed for the concentration of magnetite or the scalping of ferromagnetic materials. LIMS usually work as wet separators. These comparatively basic applications benefit from the large capacity and ease of use of the LIMS. Dry, rare-earth magnets of medium intensity are typically used.

Based drum magnetic separators (RED) are frequently used in the processing of extremely paramagnetic minerals such as limonite, chromite, and garnet. Similar to LIMS, these RED systems are reliable as they frequently give great capacity along with simple operation. Dry or wet high-intensity magnetic separators are both accessible. Induced-roll Magnetic (IRM) or Rare-Earth Roll (RER) magnetic separators can be used for high-intensity dry magnetic separations, albeit the latter is considerably more common. Although having a considerably lower capacity than low and medium-intensity magnetic separators, the RER is widely recognized to perform efficient separations with weakly paramagnetic materials. Cleaning zircon, silica sands, and a variety of other industrial minerals is where RER units are most routinely used. Wet, High-Intensity Magnetic Separators (WHIMS) produce strong magnetic fields. To extract the magnetic portion, flow the slurry through matrix topologies. In the early phases of a flow sheet, WHIMS are frequently utilized in mineral sands to collect limonite. They also have several of other popular uses, such as iron ore (haematite) beneficiation.

Moisture intrusion into lubrication systems is a common and problematic issue. It can occur through various pathways, such as the headspace entry point, seals, or even through new oil introduced into the system. Once inside, moisture can manifest in different forms within the lubricant, each with its detrimental effects. Moisture is a pervasive contaminant that can enter lubrication systems through multiple routes. Its presence can lead to significant degradation of lubricant performance and machinery health. Emulsified water, in particular, poses the greatest threat due to its ability to cause lubrication failure and mechanical wear. To maintain effective lubrication and prolong equipment life, it is crucial to monitor and control moisture levels in lubrication systems.

5.1. Implementation of Oil Extraction

For the extraction of distinctive characteristics from vibration signals gathered from induction machines subjected to bearing fluting, the Continuous Wavelet Transform (CWT) is applied. Thermal aging and Electrical Discharge Machining (EDM) were used to synthetically generate the bearing's flaws.

Short-Time Fourier Transform was contrasted with the suggested approach, and it was shown that the CWT has several advantages. The authors were able to recover tiny amplitudes from the CWT that are imperceptible along the frequency axis. They also identified between 2 and 4 kHz. Several inverter-fed induction machines' broken bars and bearing faults (inner race defect) have been investigated using a new hybrid approach that combines the study of the time- and frequency-domain signal. To analyze stator current features, this innovative technique combines Independent Component Analysis (ICA) with FFT.

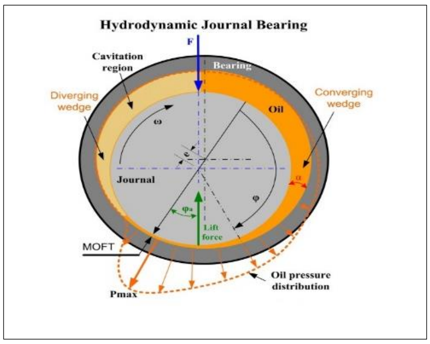

Figure 5. Dynamic modeling of material and substance flow [29]

ICA is a statistical method for breaking down a complex dataset into separate components. According to the authors, the suggested technique accurately detects and categorizes the typical fault frequency components. The detection of bearing defects is more challenging. The dynamic modeling of material and substance flows is given in Figure 5. It has been shown that fid provides the primary characteristic fault frequency. Other writers have utilized a variety of methodologies for bearing defect identification, including neural networks, hidden Markov modeling, which is an instantaneous power factor, etc.

6. Implementation

In this section, we thoroughly examine the outcomes of the cluster analysis, aiming not just to understand the clusters formed but to specifically focus on those illustrating the extraction of fuel within the lubricant. We'll explore the implications and potential origins of fuel dilution within this context, shedding light on its effects.

Furthermore, the term 'bearing life' signifies the total number of rotations or the duration a bearing can endure before experiencing failure. Various factors contribute to bearing failure, including fractures, insufficient lubrication or greasing, and inadequate bearing stress on the shaft. By understanding these failure modes, we gain insight into the crucial elements affecting a bearing's durability and performance.

This work covers various methods for diagnosing rolling bearing damage and different failure scenarios. A significant cause of failure in hydraulic systems is fluid contamination. The clustering result is given in Table 2 that said, there are hydraulic systems that intentionally use water as the design fluid and there is oil in water systems for various uses. The majority use specific hydraulic fluid that is less susceptible to temperature effects and provides lubrication properties. Transmission fluid can be classified as either a hydraulic fluid or a lubricant, depending on the transmission type. Understanding how much water it takes to cause problems is the key to service and prevention. Much like the relative humidity in air, oils can hold more water molecules are the temperature increases. This is directly related to the energy of the individual molecules, which allows them to move more freely and independently. This can pose specific challenges for oil moisture management, as operating temperatures are always higher than resting temperatures.

During operation, water contamination can be absorbed without separation, only to separate and form free water when the machines stop, and temperatures decrease. Moisture is a known contaminant in a wide variety of applications, but moisture in industrial oil can be particularly damaging. In addition to impacting oil performance, water degrades additives and film strength, thus presenting the opportunity for mechanical wear and corrosion.

Table. 2 Clustering result

Cluster 1		Cluster 2		Cluster 3		Cluster 4		Outliers	
Signal No	Bearing Type	Signal No	Bearing Type	Signal No	Bearing Type	Signal No	Bearing Type	Signal No	Bearing Type
56	Eroded	20	Outer ring fault	7	Well-being	43	Point Error	54	Eroded
51	Eroded	29	Outer ring fault	11	Well-being	40	Point Error	49	Eroded
59	Eroded	32	Outer ring fault	10	Well-being	39	Point Error		
50	Eroded	30	Outer ring fault	14	Well-being	35	Point Error		

47	Eroded	31	Outer ring fault	12	Well-being	41	Point Error		
52	Eroded	28	Outer ring fault	8	Well-being	34	Point Error		
55	Eroded	25	Outer ring fault	5	Well-being	44	Point Error		
48	Eroded	26	Outer ring fault	2	Well-being	38	Point Error		
46	Eroded	22	Outer ring fault	9	Well-being	37	Point Error		
60	Eroded	23	Outer ring fault	4	Well-being	42	Point Error		
58	Eroded	21	Outer ring fault	3	Well-being	36	Point Error		
57	Eroded	19	Outer ring fault	15	Well-being	33	Point Error		
53	Eroded	18	Outer ring fault	16	Well-being				
45	Eroded	24	Outer ring fault	13	Well-being				
		27	Outer ring fault	6	Well-being				
		17	Outer ring fault	1	Well-being				

Standard equipment features such as breathers are designed to evaporate moisture from the oil. The fundamental frequency values of rolling element when preventative measures fail, the water content in oil can reach. Manual sampling is time-consuming, costly, and inefficient, particularly when real-time monitoring provides better insight into changing conditions. Continuous monitoring offers several improvements over manual monitoring for lubrication, fuel and hydraulic oils, diesel, and any oil-based fluid.

An industrial facility may experience a variety of issues, including bearing failure, wear of mechanical moving parts, heat damage from friction, foaming, sludge manufacturing, metallic corrosion, and additive depletion. The presence of moisture in oil can be linked to each of these particular effects. The key to effective processing is knowing the reasons why problems go wrong while taking precautions that are required to prevent them.

The different tools to be considered for the analysis. A vacuum dehydrator, Humidity and temperature transmitter, air compressor filters. Analyzing the detailed study of the existing manufacturing system and the objectives will be concluded in the cluster analysis. The latest in polymer technology has been integrated with a restricted essential feature auto-calibration to alleviate an issue of sensor drift in highly dehydrated issues. Investigating the industrial impact of coolant oil contamination is given in Figure 6.

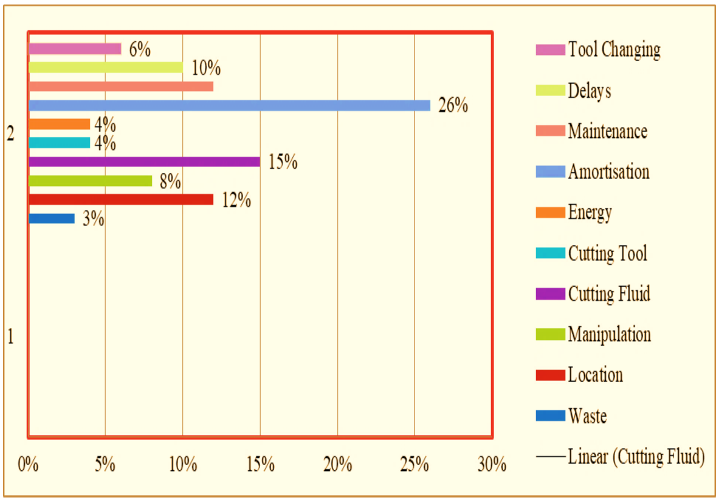

Figure 6. Investigating the industrial impact of coolant oil contamination

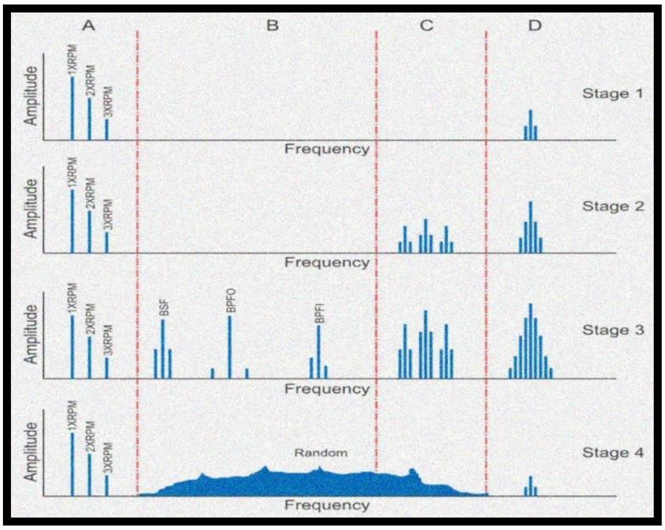

Figure 7. Frequency spectrum for bearings that rotates 287rpm

7. Frequency Signal Classification

In the previous section, we analysed frequency spectrums from various bearing conditions. Using principal component analysis (PCA), we examined the frequency spectrums of healthy bearings, bearings with point defects, outer race defects, and corroded bearings. Figure 7 shows the frequency spectrum for bearings rotating at

287 rpm. Our analysis revealed that the principal components (PCs) of these spectrums form four distinct groups, which are shown in the sub-figures. Figure 8 illustrates a dendrogram plot of principal components 1 and 2, highlighting the clustering of these different bearing conditions. Remarkably, these components formed a clustered pattern resembling ellipsoids. This clustering occurred due to similarities present in the dataset's patterns. Essentially, these ellipsoidal-shaped clusters signify that each set of scattered data belongs to a particular group of bearing types. This observation strongly suggests that these ellipsoidal patterns encapsulate the distinct characteristics of each bearing type.

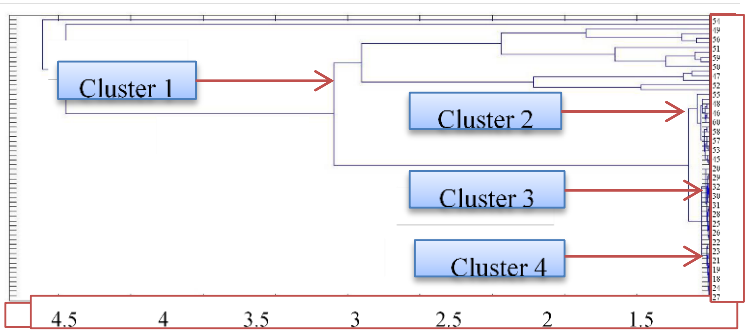

Figure 8 Dendrogram plot of principle components 1 and 2

8. Results and Discussion

Optical inspections of tested bearings corroborate the vibration analysis results. In the first set of tests with steel particles, bearings showed less damage despite longer operation compared to the second set. The hardness of grease contaminants is crucial, influencing wear and failure mechanisms. Particle movement in and out of the contact zone is driven by their concentration and contaminated grease flow. Entering the contact zone, particles deform under high stress. Figure 9 shows bearing ring failure due to oil contamination, with ductile particles like steel forming round flakes, while brittle particles crush or penetrate surfaces depending on their rigidity. Several crucial observations emerge from this analysis. Across all CLS (Contamination Level Severity) conditions, a consistent trend is observed: vibration levels rise with contaminant concentration, seemingly stabilizing beyond a certain threshold, approximately 4.5 times the vibration observed in clean oil. Additionally, comparing the first and last sets of columns in the graph concerning contaminated conditions reveals intriguing insights. Table 3 outlines the vibration levels in the W3S2 CLS condition for a bearing rotating at 287 rpm, measured at 2 and 16 minutes into the test for all studied contaminant concentrations. Despite the relatively short test duration under contaminated oil, a noticeable increase in vibration is evident across all concentration levels, emphasizing the impact of contaminants on bearing performance.

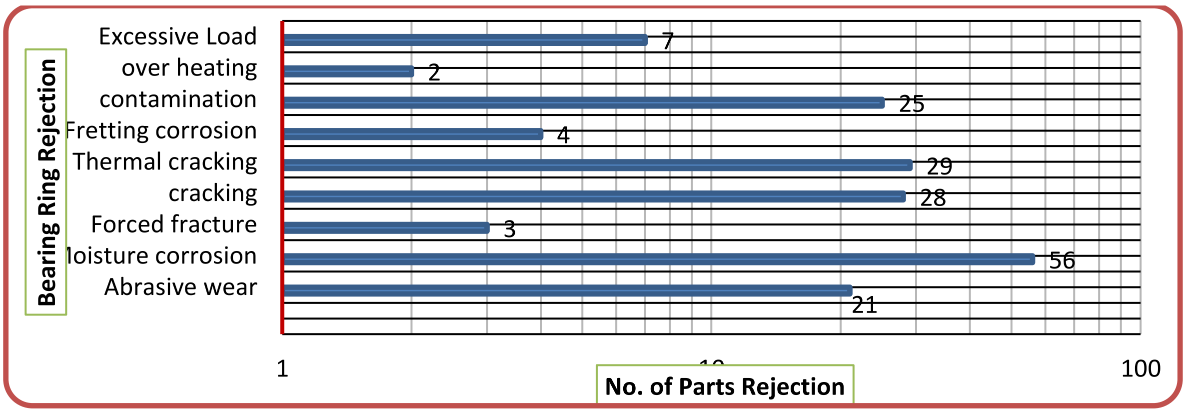

Figure. 9 Bearing ring failure due to oil contamination

Periodic Waveform	Value (Hz)
Outer Race Ball Passing Frequency, BPFO	13.65
Inner Race Ball Passing Frequency, BPFI	24.58
Basic Train Frequency, FTF	1.707
Ball Spin Frequency, BSF	1.67

Table 3. Fundamental frequency of bearing which rotates at 286 rpm

9. Conclusion

The current techniques in monitoring machinery faults cover a wide range of issues, from broken rotor bars and shorted windings to air-gap eccentricity, bearing faults, and load irregularities. In the upcoming section, we will explore the results from a cluster analysis. Our focus will be on presenting and interpreting the clusters identified, with particular attention to those clusters that indicate the presence of fuel extraction in the lubricant. This analysis will help us understand the patterns and implications of fuel contamination in the lubrication system. Additionally, we'll extensively explore the impacts and potential origins of fuel dilution within this context. This exploration isn't just about identifying clusters; it's about understanding what these clusters signify, particularly about fuel extraction in the lubricant. Moreover, we're delving into the effects caused by this fuel dilution and investigating the potential sources triggering this phenomenon. This deeper analysis will shed light on the complexities surrounding the presence of fuel in the lubricant and its implications for machinery performance.A comprehensive lubrication and fluid management program includes contamination control, monitoring, analysis, and maintenance. Precise measurement and control begin with quality sensors that are accurate and dependable and end with efficiency that directly affects the bottom line. Instituting active and accurate monitoring can help identify sources of ingress while taking the burden off an analysis program. Predictive maintenance can then provide significant cost savings by extending the life of the equipment and minimizing unexpected downtime the traditional and current method for oil monitoring has been through sampling and laboratory analysis. No other method will provide a more complete set of tests to determine the total quality and chemical makeup of oil there are limitations and challenges associated with this method, especially when it comes to measuring water content. Collecting and analyzing samples can be a lengthy process, and collection methods can potentially expose samples to the atmosphere or other sources of contamination. This method not only reduces the risk of human-induced error but also provides cost savings.

10. Future Scope and Limitations

Optimal lubrication plays a crucial role in maintaining bearings, aiding in reducing slippage and churning while mitigating various types of wear that could otherwise accelerate part failure. Identifying the most suitable lubricant for your specific part becomes the cornerstone of this process. Inadequate or improper lubrication can significantly hasten the wear and tear of bearings, potentially leading to their premature failure. Choosing the right lubricant is the key to ensuring the longevity and optimal functioning of these components. When dirt or dust infiltrates the bearing's raceway, it mixes with the lubricant, leading to contamination. This contamination can cause increased wear, higher friction, and potential bearing failure. Preventing this is crucial for maintaining the bearing's performance and lifespan. Selecting the right sealing mechanism is essential. The seal must be capable of retaining the lubricant inside the bearing while also preventing external contaminants from entering. Effective seals, such as rubber or metal seals, ensure that the oil lubricant remains in place and clean, providing consistent lubrication to reduce wear and tear. Using conventional lubrication methods with the right type of oil or grease reduces friction between the bearing components. This lubrication helps in dissipating the heat generated from the bearing’s operation, ensuring smooth functioning and preventing overheating. Proper lubrication also minimizes direct contact between metal surfaces, reducing wear and prolonging the bearing's service life.

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