International Journal of Engineering Research and Sustainable Technologies
Volume II, No.1, March 2024, 16 - 28
ISSN: 2584-1394 (Online version)

ANALYSIS OF BEARING FAILURE DUE TO COOLANT OIL CONTAMINATION USING DIAGNOSTIC TECHNIQUES IN GRINDING

Sriram Pranatharthi Haran[*a]
[*a]CEO Sriram Pranatharthi Haran, CBMM Supply Services and Solutions PTE Ltd, Singapore
*** Corresponding author email address**: Sriram@cbmmgroup.com

https://doi.org/000000/000000/

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 time period) 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 contaminate 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, 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. Damage spread A cylindrical roller bearing's inner ring raceway was scratched by a hard contaminant after being over-rolled (a). Just behind the indentation, a surface-initiated fatigue that ultimately contributed to a spill occurred. Spilling gradually increased in harshness over time (b, c). 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. 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.

1.1. 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 its high purity functioning. In a machine of the Double Drum kind, the material will go through the magnet twice. In order 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 and entirely enclosed designs. According to need, online fitting design is also available.

1.2 Data Sample and Collection

This study is based on five years of used oil analysis data collected from an anonymous power plant, encompassing over 1,000 samples. Each sample was tested for 20 different variables in an internationally accredited laboratory.

1.3 Data preparation

The collected data underwent a thorough cleaning process to address missing entries and involved expert evaluation to assess and manage outliers. Separate results were consolidated into a single cohesive dataset prepared for analysis. To ensure consistency, the data was standardized, as the variables were originally measured on different scales.

Table 1. Analysis of Ball Bearing Damage

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

2. Related Work

A rolling-element bearing typically consists of two rings between which a series of rollers or balls rotate. The majority of the time, bearing failures arises by the bearing's substance wearing out. Small cracks that is present inside the surfaces of the raceway and rolling components are 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. 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 a number of 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. Figure 1 shows the usual design and dimensions of a ball bearing. A cage that prevents contact between the balls and maintains a constant distance between them fixes and holds the balls together.

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. Material deterioration, overheating, severe conditions, poor storage, contamination, corrosion, improper handling and installation, etc., can all lead to bearing failures. However, insufficient lubrication, which can be easily avoided with the right maintenance strategy, is the primary reason for their failure. Typically, vibration-based monitoring techniques are used to diagnose the sensors and specialized tools are used to monitor the condition. 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.

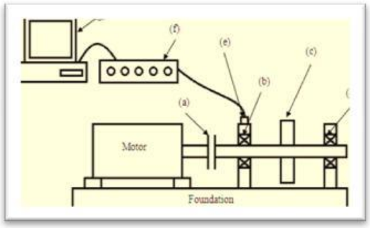

Fig.1.Experiment setup.

Table.2 Component Parts

	Part/Component
a	coupling
b	bearing
c	Flywheel
d	Supporting bearing
e	Seismometer
f	DAQ
g	Analyzer

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. 1) Review of relevant literature on failures. 2) Possibilities for failures when grinding. 3. 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 total quality and chemical make-up of oil. 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 to 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 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 saturation point, which doesn't allow for real-time control of processes makes 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 it 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 down 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 analyzed 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 investigation of the first defect reveals two components: |fess food| and |fess 2fod| in the current spectrum and food and 2fod in the vibration spectrum. The highlighted characteristics for the second type of fault are [fess food], [fess 2fod], and [fess fid], correspondingly, for the vibration spectrum and current spectrum. The writers in this work present an unusual strategy for the spectrum analysis being used at the present time to identify bearing failures in induction motors powered by frequency power converters. The authors point out a rise in the specific fault frequency variation components of the current spectrum and identify the fault as an outer race defect. Vibration and current analysis are used for the investigation of two inner raceway faults (drilled holes and spalls). The findings illustrate that only the vibration spectrum can clearly display the fault frequencies. 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 saturation point, which doesn't allow for real-time control of processes makes 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 it also saves money on labour, 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.

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 down 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 analyzed 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.

This does not account for the form of the water, the oil's temperature or saturation point, which doesn't allow for real-time control of processes makes 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 it 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. 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 down and evaluate it using several approaches, including Fourier statistical analysis, wavelets, neural networks, etc The authors analyze two types of bearing faults: a hole drilled into the outer raceway and an indentation made on the inner and outer surfaces. They use vibration and current analysis to investigate both types of faults, highlighting the precise characteristic fault frequencies for each issue.

4. Cluster Analysis – Statistical Analysis

Cluster analysis is a statistical method used to group objects or observations into clusters based on their similarities. The objective is to make each cluster as homogeneous as possible with respect to the clustering variables, while ensuring that clusters differ from each other based on specific characteristics. There are two main types of cluster analysis: hierarchical and non-hierarchical techniques. Hierarchical techniques involve creating a tree-like structure of nested clusters, where each level of the hierarchy represents a different level of similarity among the objects. 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 own unique clusters in agglomerative methodologies. Repeatedly merging the two "closest" (most similar) clusters results in an amalgamation of all variables into one cluster. Finally, among all cluster solutions, the most effective number of clusters is picked. The clustering process is used in reverse until each topic is in its own group when using the divisive methods, where all variables are clustered into the same cluster. Due of their usefulness, aggregative strategies are more frequently utilized than divisive ones. b) Non-hierarchical approaches (commonly referred to as kmeans clustering methods) with these methods, the 'best' solution is selected and the desired number of clusters is stated in advance. There are certain limitations to cluster analysis, such as the fact that since it is a heuristic technique, clusters may form even when there isn't an organized set of variables in the data.

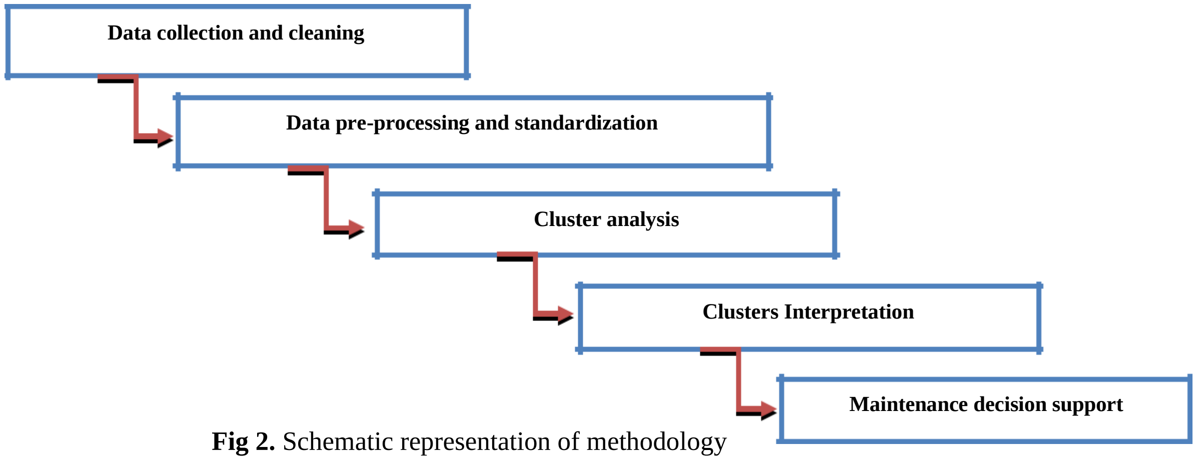

Fig 2. Schematic representation of methodology

When using procedures like external cross validation, clustering can frequently produce groups from noise in the data that may have originally been a sampling error or sample procedure error. For this reason, demonstrating the reliability of the grouped variables is crucial. In the context of cluster analysis of lubricant data in practice, the uncertainty of inferences induced by sampling error of data has not typically been assessed. In order to construct clusters with a degree of certainty, we want to evaluate the level of uncertainty in this study. Probability values (p-values) for each cluster in hierarchical clustering are identified via a multistage bootstrap resampling. 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-clust R software function [19] estimates probability values (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. Additionally, using the parallel computing option can significantly cut down on processing time. To evaluate the uncertainty in hierarchical cluster analysis, Pv-clust executes bootstrap analysis on the statistical software R [20]. In phylogeneticanalysis, a special type of hierarchical clustering used to reconstruct the history of evolution as a dendrogram [20], its significance of uncertainty evaluation has long been acknowledged. Clusters comprising AU p-v Values greater than 95% have been considered or adjudicated to have substantial support from the data. When a number of variables do not follow a normal distribution, as was the case in the data used for this study, this method facilitates the use of Spearman's correlation coefficient, which is appropriate.

4.1 Maintenance decision support

The author discusses draw 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 prior to 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 by 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. prior washing. Add system cleaner to the cutting fluid before draining. Cutting fluid system with fresh emulsion Drain the tank refill cutting fluid system.

4.2 Material

AISI52100 alloy steel serves as a widely utilized material for rolling contact bearings due to its notable attributes. It boasts high compressive strength, making it adept at withstanding heavy loads. Additionally, its affordability renders it economically viable for various applications. The steel exhibits commendable wear resistance, ensuring prolonged durability under demanding conditions. Moreover, AISI52100 steel demonstrates excellent corrosion resistance, particularly in oxidation and acidic environments. Its chemical, mechanical, and thermal properties collectively contribute to its suitability for bearing applications, making it a preferred choice in diverse industrial settings.

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. 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 to the initial investment expenses and on-going maintenance costs. It is recommended that tests be conducted on the system ahead under actual world conditions to prevent unpleasant surprises afterwards. 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 moisture given into the housing depends on the temperature, oil 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 colour 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 is shown in the image. This kind of technology would prevent too much water from seeping into the oil when used with sufficient bearing housing seals.

4.4 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 up 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 for 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 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 (IRM) or rare-earth roll (RER) magnetic separators can be used for high intensity dry magnetic separations, albeit the latter is considerably more common (Dobbins, Sherrill 2009). 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. In order 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.

Fig 3. Oil contamination filter

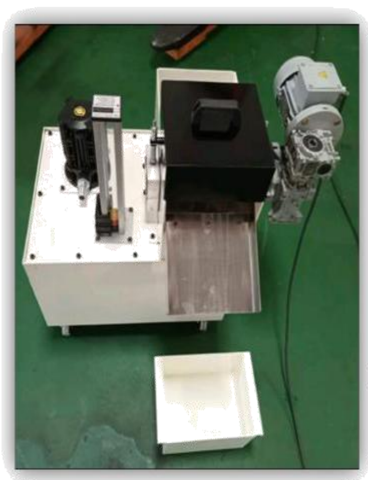

Fig .4 After grinding process remove grinding particle from coolant oil

Fig.5 Image of a typical hand refract meter used to measure fluid concentration

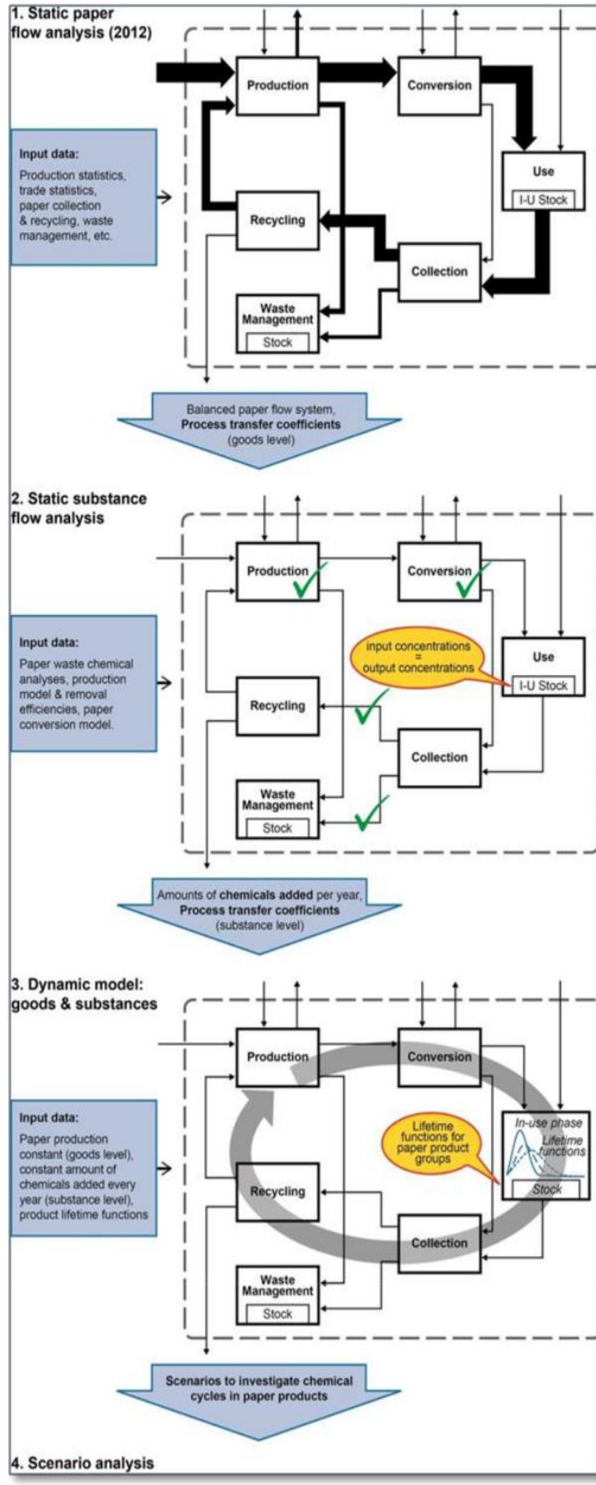

Fig. 6 Dynamic Modelling of Material and Substance Flows

Moisture infiltration into a system can occur via various pathways, such as through the headspace entry point, seals, or during the introduction of new oil. In environments where the headspace is humid, thermal fluctuations may prompt moisture to condense and seep into the oil through gravitational forces. Within a lubricant, moisture can exist in different forms: dissolved, emulsified, or free water. Emulsified water, in particular, poses the greatest risk as it can cause severe damage to the oil.

Water lacks lubricating properties, so when it displaces oil within a bearing's load zones, it leads to lubrication breakdown and mechanical wear. Additionally, water accelerates processes like oxidation and hydrolysis, resulting in permanent chemical degradation and depletion of additives within the lubricant. These factors can alter the lubricant's viscosity, compromise additive effectiveness, and foster the formation of insoluble contaminants and acids. Moreover, water serves as the primary catalyst for rust formation in machinery.

In summary, the presence of water in lubricants can instigate a cascade of detrimental effects, ranging from lubrication failure and mechanical wear to chemical degradation and corrosion, ultimately jeopardizing the efficiency and longevity of machinery.

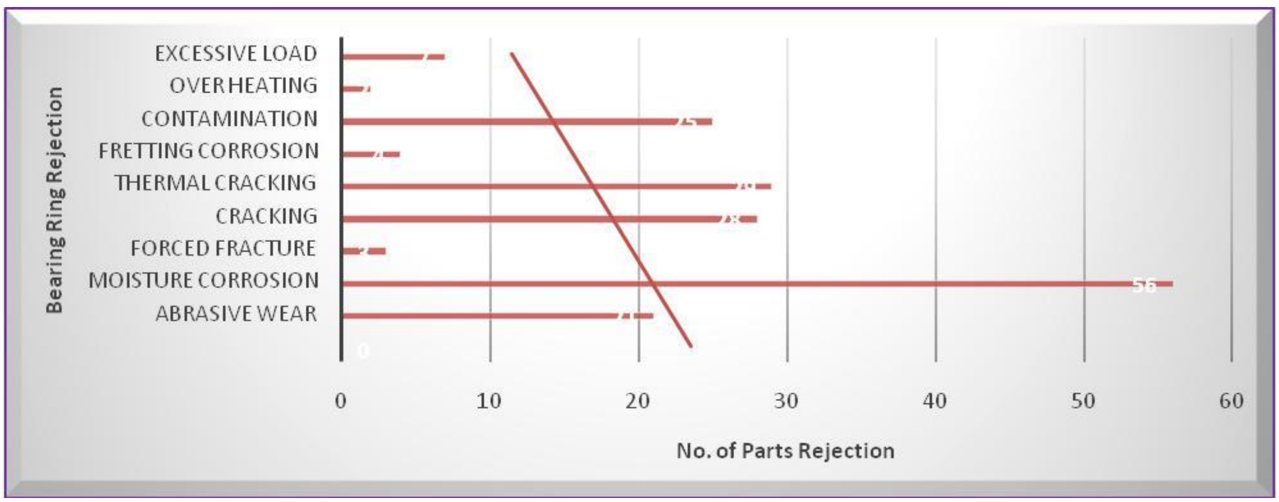

Fig. 7 Bearing ring failure due to oil contamination

5. Implementation

This section reviews the cluster analysis results, interprets the clusters created, and delves deeper into the clusters that demonstrate the lubricant's fuel extraction. Effects and probable causes of the fuel dilution are also investigated. The term "bearing life" refers to the total number of revolutions (or time period) a bearing can withstand before failing. Fractures, inadequate lubrication and greasing and not sufficient bearing stress on the shaft are common failure modes. The work presented here spans several rolling bearing damage diagnosis methods and failure scenarios. One of the main causes of failure in hydraulic systems is fluid contamination. 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 contaminate 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, 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, and 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 knows 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. As course work, two papers (a) Research Methodology (b) Term paper leading to the thesis- has to be successfully completed. Analyzing the detailed study of existing manufacturing system and the objectives will be concluded in the cluster analysis. Solution was to combine the highest quality polymer technology with a patented key feature – auto-calibration – that would eliminate sensor drift in very dry conditions.

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, ranging this innovative technique combines Independent Component Analysis (ICA) with FFT. 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. 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 modelling, which is instantaneous power factor, etc.

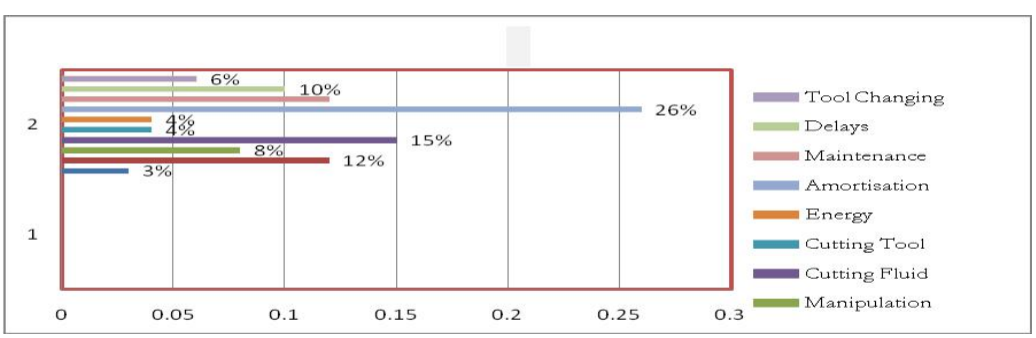

Fig. 7 Investigating the industrial impact of coolant oil contamination

6. Results and Discussions

The optical inspections of the tested bearings align with the findings from vibration analyses. Notably, the bearings subjected to the first set of tests, involving steel particles, exhibit lesser damage compared to those in the second set, despite the latter undergoing longer operating durations. The hardness of the grease particle contaminants holds significant importance as it dictates the wear and failure mechanism.

Particles ingress and egress the contact zone based on their concentration levels and the flow of contaminated grease. Upon entering the contact zone, particles undergo deformation due to high stresses. Ductile particles, exemplified by steel particles, tend to roll over, forming rounded flakes. Conversely, brittle particles are crushed, or if rigid enough, they may penetrate the contact surfaces.

Several key observations emerge from the analyses. Firstly, across all conditions of Contaminant Load and Size (CLS), vibration levels demonstrate a consistent increase with contaminant concentration, seemingly plateauing at higher concentrations up to a certain threshold. This threshold typically reaches approximately 4.5 times the vibration level observed in clean oil. Secondly, a comparison between the initial and final sets of columns for contaminated conditions reveals notable increases in vibration levels, particularly evident in the W3S2CLS condition, regardless of the duration of test time under contaminated oil. These findings underscore the significant impact of contaminant concentration on vibration levels and subsequent bearing performance.

Table3 . Fundamental Frequency of Rolling Element Bearing which rotates at 287rpm.

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

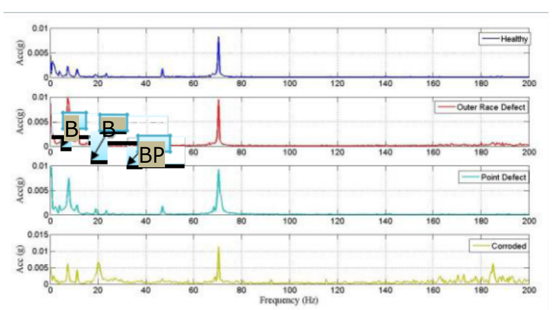

Fig.8. Frequency spectrum for bearings that rotates *287 rpm*

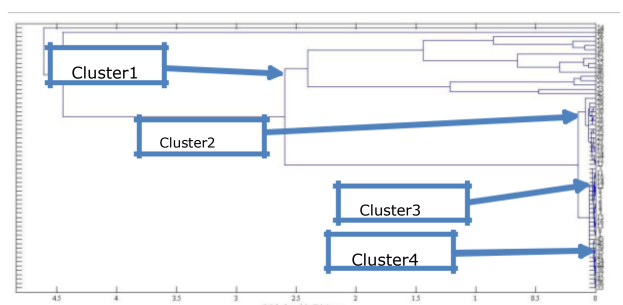

Fig. 9.Dendrogramplot of principle component1and 2.

6.1 Frequency signal classification

In the previous section, it was evident that the frequency spectrum of each bearing condition exhibited distinct structural differences. To effectively represent and cluster these spectra, Principle Component Analysis (PCA) was employed on a dataset comprising healthy bearings, bearings with point defects, outer race defects, and corroded bearings. The results are depicted in Fig. 3.

Fig. 3(a) displays the scatter plot of Principle Component 1 and Principle Component 2, providing an overview of the data distribution, while Fig. 3(b) zooms in on a specific section of the plot. Both sub-figures reveal that the principle components derived from the frequency spectra are dispersed into four distinct groups. Notably, these scattered data points form ellipsoidal shapes, suggesting a grouping or clustering pattern.

This scatter trend is attributed to the similarities present in the patterns of the tested dataset. Essentially, each ellipsoidal-shaped cluster of data is presumed to correspond to a specific group of bearing types. This finding underscores the effectiveness of PCA in discerning and grouping frequency spectra based on bearing condition, facilitating the identification and classification of different types of bearing faults.

Table. 4 Clustering Result

Cluster1		Cluster2		Cluster3		Cluster4		Outliers	
Signal No	**Bearing Type**	**Signal No**	**BearingType**	**Signal No**	**Bearing Type**	**Signal No**	**Bearing Type**	**Signal No**	**Bearing Type**
56	Corroded	20	OuterRaceDefect	7	Healthy	43	PointDefect	54	Corroded
51	Corroded	29	OuterRaceDefect	11	Healthy	40	PointDefect	49	Corroded
59	Corroded	32	OuterRaceDefect	10	Healthy	39	PointDefect		
50	Corroded	30	OuterRaceDefect	14	Healthy	35	PointDefect		
47	Corroded	31	OuterRaceDefect	12	Healthy	41	PointDefect		
52	Corroded	28	OuterRaceDefect	8	Healthy	34	PointDefect		
55	Corroded	25	OuterRaceDefect	5	Healthy	44	PointDefect		
48	Corroded	26	OuterRaceDefect	2	Healthy	38	PointDefect		
46	Corroded	22	OuterRaceDefect	9	Healthy	37	PointDefect		
60	Corroded	23	OuterRaceDefect	4	Healthy	42	PointDefect		
58	Corroded	21	OuterRaceDefect	3	Healthy	36	PointDefect		
57	Corroded	19	OuterRaceDefect	15	Healthy	33	PointDefect		
53	Corroded	18	OuterRaceDefect	16	Healthy				
45	Corroded	24	OuterRaceDefect	13	Healthy				
		27	OuterRaceDefect	6	Healthy				
		17	OuterRaceDefect	1	Healthy				

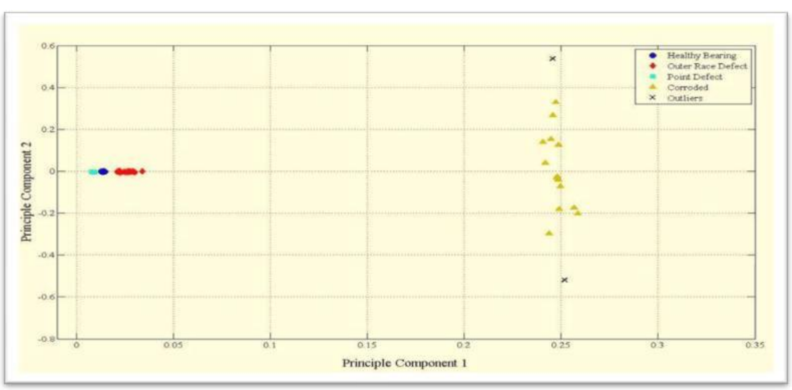

Fig. 10. Principle Components scatter plot with cluster group.

7. Conclusion

Contaminants such as particulate matter, water, and chemical residues significantly contribute to bearing wear and failure by disrupting the lubrication film and increasing friction. Identified increased vibration levels and specific frequency patterns that signal bearing faults, effectively diagnosing degradation. Revealed the presence of contaminants like metal particles and other debris, confirming oil contamination. Detected elevated operational temperatures in contaminated bearings, indicating compromised lubrication and higher friction. Captured high-frequency noise indicative of early bearing wear, enabling pre-emptive maintenance actions. Accelerated wear and premature bearing failure were directly linked to coolant oil contamination, evidenced by surface degradation, pitting, and spalling of bearing components. Contaminants also caused corrosion and chemical degradation, further exacerbating bearing wear. Regular coolant oil quality monitoring through comprehensive oil analysis to detect early contamination.

Implementing effective filtration systems to remove particulates and water from the coolant oil. Adhering to a strict maintenance schedule and timely replacement of contaminated oil to extend bearing life. Utilizing diagnostic tools such as vibration analysis, thermography, and acoustic emission for continuous condition monitoring and proactive maintenance. Establish robust maintenance protocols for ensuring coolant oil purity and effective lubrication. Integrate advanced diagnostic techniques into routine maintenance to detect and address bearing wear early. Train personnel on the critical importance of coolant oil quality and the proper maintenance of lubrication systems. In conclusion, maintaining coolant oil quality is crucial for preventing bearing failures in grinding operations. The application of advanced diagnostic techniques allows for early detection and intervention, thereby enhancing the reliability and efficiency of the equipment. This proactive approach minimizes downtime and maintenance costs, ensuring optimal operational performance.

References

1. Bhadeshia, H. Steels for Bearings. *Prog. Mater. Sci.* **2012**, *57*, 268–435. [**Google Scholar**] [**CrossRef**]
2. Hwang, Y.-K.; Lee, C.-M. A Review on the tightening axial force Technology of the Rolling Bearing for the Spindle of Machine Tools. *Int. J. Precis. Eng. Manuf.* **2010**, *11*, 491–498. [**Google Scholar**] [**CrossRef**]
3. Madar, E.; Galiki, O.; Klein, R.; Bortman, J.; Nickell, J.; Kirsch, M. A New Model for Bearing Spall Size Estimation Based on Oil Debris. *Eng. Fail. Anal.* **2021**, *134*, 106011. [**Google Scholar**] [**CrossRef**]
4. Kishore, K.; Mukhopadhyay, G. Root Cause Failure Analysis of Pinch Roll Bearing at Hot Strip Mill. *J. Fail. Anal. Prev.* **2019**, *19*, 219–229. [**Google Scholar**] [**CrossRef**]
5. Ban, J.; Liu, X.-L.; Luo, Y.; Zhao, Q. Cause Analysis and Prevention of Flaking of W9Cr4V2Mo Steel Rolling Bearing. *Fail. Anal. Prev.* **2015**, *10*, 238–242. [**Google Scholar**]
6. Tauqir, A.; Salam, I.; Haq, A.U.; Khan, A. Causes of Fatigue Failure in the Main Bearing of an Aero-Engine. *Eng. Fail. Anal.* **2000**, *7*, 127–144. [**Google Scholar**] [**CrossRef**]
7. Salam, I.; Tauqir, A.; Haq, A.U.; Khan, A. An Air Crash Due to Fatigue Failure of a Ball Bearing. *Eng. Fail. Anal.* **1998**, *5*, 261–269. [**Google Scholar**] [**CrossRef**]
8. Xu, X.-L.; Yu, Z.-W. Failure Analysis of Tapered Roller Bearing Inner Rings Used in Heavy Truck. *Eng. Fail. Anal.* **2020**, *111*, 104474. [**Google Scholar**] [**CrossRef**]
9. Iliev, H. Failure Analysis of Hydro-Generator Thrust Bearing. *Wear* **1999**, *225–229*, 913–917. [**Google Scholar**] [**CrossRef**]
10. Savaskan, T.; Veinot, D. On the Wear and Failure of High Speed Roller Bearings. *Wear* **1987**, *116*, 361–380. [**Google Scholar**] [**CrossRef**]
11. John, S.K.; Mishra, R.K.; Hari, K.; Ramesha, H.P.; Ram, K.K. Investigation of Bearing Failure in a Turbo Shaft Engine. *J. Fail. Anal. Prev.* **2020**, *20*, 34–39. [**Google Scholar**] [**CrossRef**]
12. Ejaz, N.; Salam, I.; Tauqir, A. Failure Analysis of an Aero Engine Ball Bearing. *J. Fail. Anal. Prev.* **2006**, *6*, 25–31. [**Google Scholar**] [**CrossRef**]
13. Mishra, R.K.; Muduli, S.K.; Srinivasan, K.; Ahmed, S.I. Failure Analysis of an Inter-Shaft Bearing of an Aero Gas Turbine Engine. *J. Fail. Anal. Prev.* **2015**, *15*, 205–210. [**Google Scholar**] [**CrossRef**]

14. Harris, T.A.; Barnsby, R.M.; Kotzalas, M.N. A Method to Calculate Frictional Effects in Oil-Lubricated Ball Bearings. *Tribol. Trans.* **2001**, *44*, 704–708. [**Google Scholar**] [**CrossRef**]
15. Averbach, B.L.; Bamberger, E.N. Analysis of Bearing Incidents in Aircraft Gas Turbine Mainshaft Bearings. *Tribol. Trans.* **1991**, *34*, 241–247. [**Google Scholar**] [**CrossRef**]
16. Bhat, R.R.; Nandi, V.; Manohara, V.; Suresh, S.V. Case Study on Failure of Ball Bearing of an Aeroengine. *J. Fail. Anal. Prev.* **2011**, *11*, 631–635. [**Google Scholar**] [**CrossRef**]
17. Murugesan, V.; Sreejith, P.S.; Sundaresan, P.B.; Ramasubramanian, V. Analysis of an Angular Contact Ball Bearing Failure and Strategies for Failure Prevention. *J. Fail. Anal. Prev.* **2018**, *18*, 471–485. [**Google Scholar**] [**CrossRef**]
18. Prashad, H. Diagnosis of Rolling-Element Bearings Failure by Localized Electrical Current Between Track Surfaces of Races and Rolling-Elements. *J. Tribol.* **2002**, *124*, 468–473. [**Google Scholar**] [**CrossRef**]
19. Dornfeld, D.; Lee, D.E. *Precision Manufacturing*; Springer: Berlin, Germany, 2008; pp. 1–48, 121–166. [**Google Scholar**]
20. Wang, Q.; Jiang, W.; Liu, H. Effects of manufacture and assembly errors on contact stress on the cylindrical roller bearing. *Mod. Mach.* **2016**, *4*, 32–37. [**Google Scholar**]
21. Li, T.; Kolar, P.; Li, X.-Y.; Wu, J. Research Development of Preload Technology on Angular Contact Ball Bearing of High Speed Spindle: A Review. *Int. J. Precis. Eng. Manuf.* **2020**, *21*, 1163–1185. [**Google Scholar**] [**CrossRef**]
22. Zou, L.; Zhou, Q.; Gao, L. Fracture failure analysis of G20Cr2Ni4A steel bearing roller. *Heat Treat. Met.* **2013**, *38*, 101–103. [**Google Scholar**] [**CrossRef**]
23. Mukhopadhyay, G.; Bhattacharya, S. Failure Analysis of a Cylindrical Roller Bearing from a Rolling Mill. *J. Fail. Anal. Prev.* **2011**, *11*, 337–343. [**Google Scholar**] [**CrossRef**]
24. Yu, Z.-Q.; Yang, Z.-G. Failure Analysis of Fatigue Fracture on the Outer Ring of a Cylindrical Roller Bearing in an Air Blower Motor. *J. Fail. Anal. Prev.* **2012**, *12*, 427–437. [**Google Scholar**] [**CrossRef**]
25. Halme, J.; Andersson, P. Rolling Contact Fatigue and Wear Fundamentals for Rolling Bearing Diagnostics—State of the Art. *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.* **2010**, *224*, 377–393. [**Google Scholar**] [**CrossRef**]
26. Cui, L.; He, Y.; Cai, C. Study on Profile Design of Cylinder Roller Bearing and Its Effect on Fatigue Life. *Mach. Des. Res.* **2015**, *31*, 67–70. [**Google Scholar**]
27. Gong, P.; Zhang, J.; Yu, Q.; Zheng, Y. Influence of Grinding Undercut on Rib Deformation for Inner Rings of Cylindrical Roller Bearings. *Bearing* **2s018**, *4–6*, 10. [**Google Scholar**]