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Comprehensive Analysis of Bearing Failure Modes: Mechanisms, Diagnostics, and Maintenance Strategies

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Abstract: Bearings are integral components in rotating machinery, facilitating smooth motion by supporting shafts and minimizing friction. Their performance and reliability are paramount, influencing the efficiency, safety, and longevity of mechanical systems across various industries, including automotive, aerospace, power generation, and manufacturing. Despite their robust design, bearings are susceptible to failure due to factors such as mechanical stress, thermal conditions, chemical exposure, and lubrication issues. Understanding these failure modes is essential for enhancing bearing performance and extending service life. This paper provides a comprehensive overview of common bearing failure modes, their underlying mechanisms, and characteristic features, the study categorizes failure modes into fatigue, wear, corrosion, plastic deformation, and fracture. Each mode is examined in detail, highlighting root causes such as improper lubrication, contamination, misalignment, overloading, and inadequate installation practices. The paper also discusses the bearing life rating, life formula, emphasizing the importance of accurate life predictions for effective maintenance strategies. Through systematic analysis, this study aims to equip engineers, maintenance professionals, and researchers with the knowledge to diagnose bearing failures more effectively and implement preventive measures. By understanding the progression of bearing damagefrom initial wear to catastrophic failurestakeholders can optimize maintenance schedules, reduce unexpected downtime, and improve the overall reliability of mechanical systems.
Keywords: Bearing failure modes, fatigue, wear, corrosion, plastic deformation, fracture, bearinglife rating, maintenance strategies, reliability engineering.

I. INTRODUCTION

Bearings are critical machine elements that support rotating shafts and enable smooth motion by reducing friction between moving parts. Their performance and reliability directly affect the efficiency, safety, and service life of mechanical systems ranging from automotive engines and turbines to industrial gearboxes and electric motors. Despite their robust design, bearings are subject to a variety of failure modes that can result from mechanical, thermal, chemical, or lubrication-related factors. Rolling element bearings are among the most critical components in rotating machinery, serving to support loads, reduce friction, and ensure smooth motion between moving parts. Despite their robust design and extensive use across industries such as automotive, aerospace, power generation, and manufacturing, bearings are inherently subject to failure due to the demanding operating conditions in which they function. The premature or unexpected failure of a bearing can lead to costly downtime, reduced equipment efficiency, and in severe cases, catastrophic system breakdowns. Understanding bearing failure modes is therefore essential for improving reliability, extending service life, and optimizing maintenance strategies. Bearing failures typically arise from a combination of factors, including improper lubrication, material fatigue, contamination, misalignment, overloading, or inadequate installation practices. Each failure mode leaves distinct physical and metallurgical signatures on bearing surfaces, allowing root cause analysis to identify underlying issues.

This paper presents an overview of the common bearing failure modes, their mechanisms, and the characteristic features associated with each. By systematically categorizing these failure patterns, the study aims to aid engineers, maintenance professionals, and researchers in diagnosing failures more effectively and developing preventive measures to enhance machine reliability.

Understanding bearing failure mechanisms is essential for accurate diagnosis, predictive maintenance, and the design of more reliable systems. Failures can manifest in different forms such as surface fatigue, wear, corrosion, plastic deformation, or fracture, each with distinct root causes and characteristic damage patterns. These modes are often influenced by factors including improper installation, inadequate lubrication, excessive loads, contamination, and misalignment.

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A study of bearing failure modes not only aids in identifying the underlying causes of malfunction but also contributes to improving bearing design, optimizing maintenance strategies, and minimizing unexpected downtime. This paper provides an overview of the most common bearing failure mechanisms, their characteristic features, and the contributing factors that lead to premature bearing degradation.

II. UNDERSTANDING BEARING LIFE AND FAILURES

Billion bearings are manufactured around the world Only a small fraction of all bearings in use actually fail(Figure-1), Some 90% outlive the equipment in which they are installed A number of bearings (9,5%) are replaced prior to failure for security (preventive) reasons Approximately 0,5% of bearings are replaced because they are damaged or fail This means that some 50 000 000 bearings are replaced every year due to damage and failure

Some reasons why bearings can be damaged or fail

33% bearing fail due to fatigue

Other 33% fail due to lubrication problems (wrong lubricant, wrong quantity wrong lubrication interval)

17% bearings fail due to contamination (ineffective seals)

Other 17% fail for other reasons (improper handling and mounting, heavier
or different loading than anticipated, wrong or inadequate fits).

In mostly industry, for example, a major cause of bearing failure is contamination and inadequate lubrication, not fatigue Each of these events produces a unique damage imprint, called a pattern Consequently, by examining a damaged bearing carefully, it is possible, in the majority of cases,

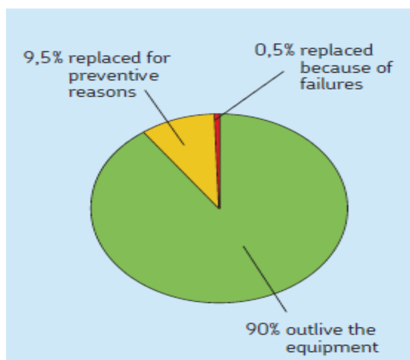


Figure-1: Bearing Life and Failure

For find the root cause of the damage Based on the findings, corrective actions can be taken to prevent a recurrence of the problem.

For application with ineffective seals When contaminants in the form of particles get into the bearing through the seals, they can be over-rolled by the rolling elements The over-rolling creates indentations in the raceways, Hard particles (Figure-2) may cause indentations with sharp edges When the area around the indentation is then subject to cyclic stress due to normal over-rolling by the rolling elements, surface fatigue is initiated and the metal will start to break away from the raceway This is called spalling Once spalling has occurred, damage will progress until the bearing becomes unserviceable.

Factors influencing bearingservice lifeGenerally speaking, the rating life of a bearing

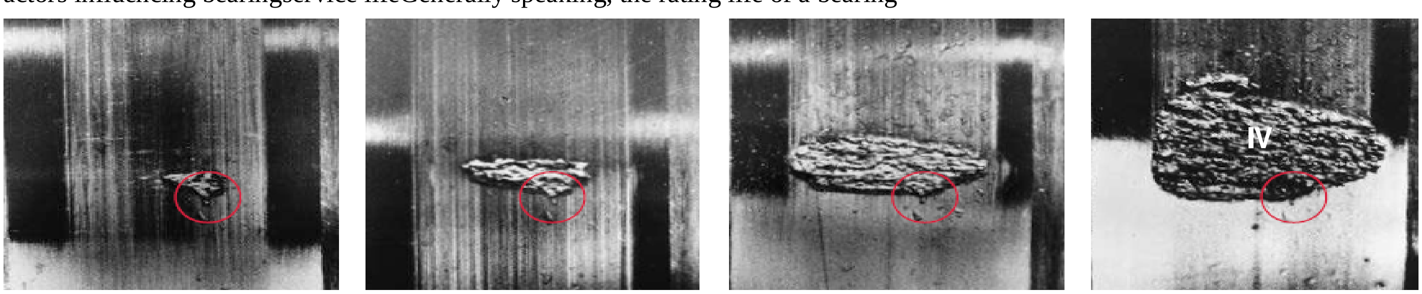


Figure-2: Damage progression A hard contaminant was overrolled and made an indentation in the inner ring raceway of a cylindrical roller bearing (I). The surface-initiated fatigue resulting in a spall started just behind the indentation. Over a period of time, spalling became more and more pronounced (II, III). If the machine was not stopped in time, secondary damage to machine components could have occurred. The initial indentation is no longer recognizable (IV).

in an application can be calculated based onthe bearing rating life formula:

$L_{nm} = a1\ a_{mf\ (C/P)}{}^{p}$

where

Lnm = bearing rating life (at 100 – n1) % reliability)
[millions of revolutions]
a1 = life adjustment factor for reliability
a_{mf}= Life modification factor
C = basic dynamic load rating [kN]
P = equivalent dynamic bearing load [kN]
p = exponent of the life equation

III. RIGHT TIME TO REPLACE THE BEARING

The amount of time from the first (initial) damage until the bearing becomes unserviceable can vary considerably At higher speeds, it can take a few seconds In large, slow rotating machines, it can take months The question, "When should I replace the bearing?", is best answered by monitoring the condition of the bearing If a damaged bearing goes undiagnosed, and is not replaced before it fails catastrophically, secondary damage to the machine and its components can result Also, when a bearing fails catastrophically, it can be difficult, even impossible, to determine the root cause of the failure

Inspection during operation

Early indications of bearing damage enable a user to replace bearings during regularly scheduled maintenance, avoiding otherwise costly unscheduled machine downtime due to bearing failure Important parameters for monitoring machine condition include noise, temperature and vibration Bearings that are worn or damaged usually exhibit identifiable symptoms Many possible causes could be responsible and need to be investigated.

For practical reasons, not all machines or machine functions can be monitored using advanced systems In these cases, trouble can be detected by looking at or listening to the machine Using the human senses to detect machinery problems, however, has limited benefit By the time sufficient deterioration has occurred for the change to be noticeable, the damage may already be extensive The advantage of employing objective technologies, such as advanced vibration analysis, is that damage is detected at an early stage of development, before it becomes problematic Figure-3

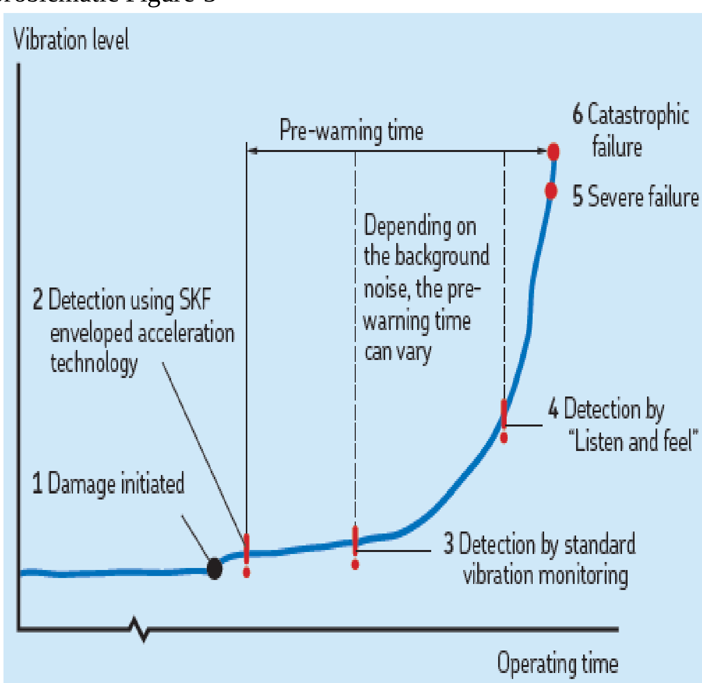


Figure-3: Advanced CBM advantage

Figure-4: Bearing damage progression

Progress of Damage as shown in Figure-4

1) Bearing exhibits incipient abrasive wear.
2) First spall, detected by SKF enveloped accelerationtechnology
3) Spalling has developed to an extent that the damage can be detected by standard vibration monitoring
4) Advanced spalling causes high vibration and noise levels and an increase in operating temperature
5) Severe damage occurs: fatigue fracture of the bearing inner ring
6) Catastrophic failure occurs with secondary damage to other components

FAILURE MODE CLASSIFICATION

There is a large number of bearing manufacturers and there are many publications on bearing damage and failure Different publications may classify bearing damage and failure in different ways and use differing terminology.

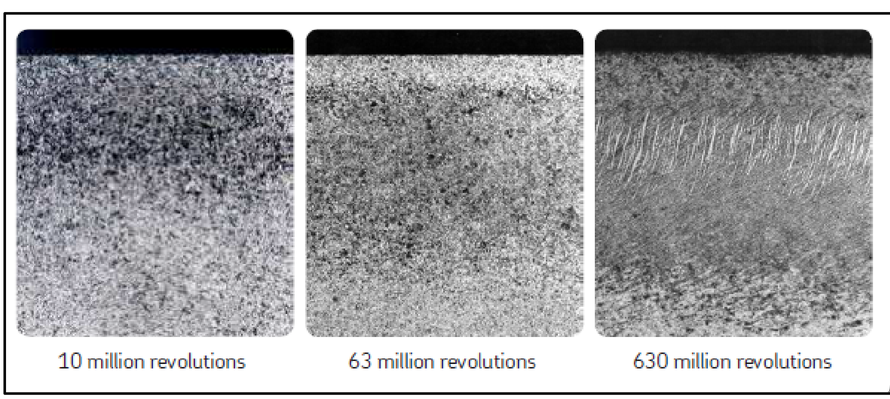
IV. FATIGUE

In a rotating bearing, cyclic stress changes occur beneath the contact surfaces of the raceways and rolling elements

Consider the rotating inner ring of a radial bearing with a radial load acting on it As the ring rotates, one particular point on the raceway enters the load zone and continues through an area to reach a maximum load (stress) before it exits the load zone During each revolution, as that one point on the raceway enters and exits the load zone, compressive and shear stresses occur Depending on the load, temperature and the number of stress cycles over a period oftime, there is a build-up of residual stresses that cause the material to change from a randomly oriented grain structure to fracture planes.

A. Subsurface initiated fatigue

In these planes, so-called subsurface microcracks develop beneath the surface at the weakest location, around the zone of maximum shear stress, typically at a depth of 0,1 to 0,5 mm (figs.5 and 6) The depth depends on the load, material, cleanliness, temperature and the microstructure of the steel



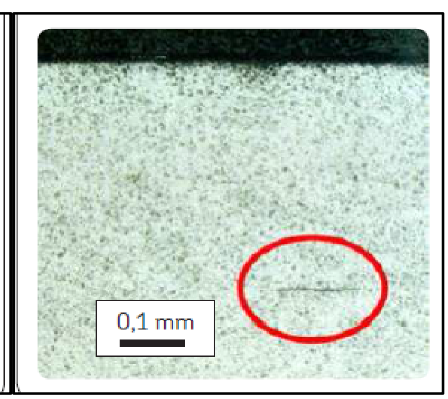


Figure-5: Changes in structure beneath the raceway surface over time   Figure-6: Crack development beneath the raceway surface

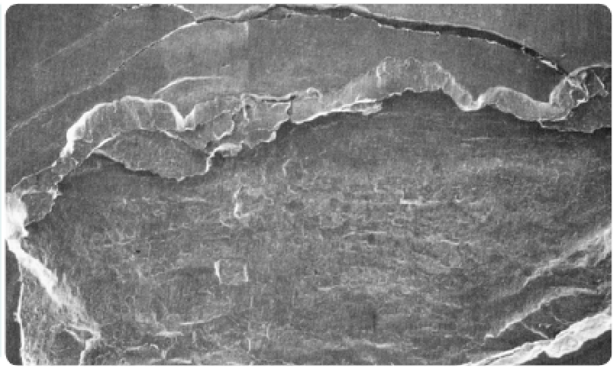


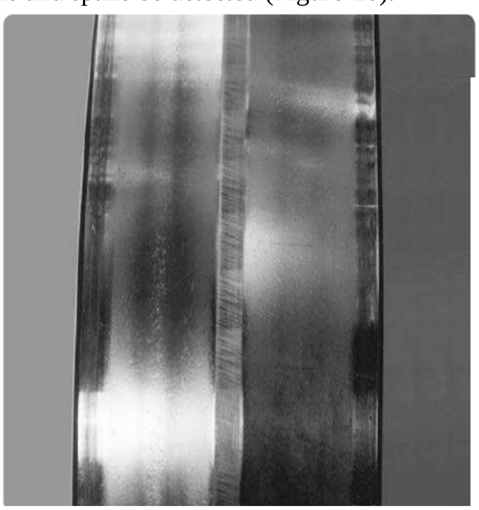
Figure-7: Initial subsurface spalling on the inner ring of a deep groove ball bearing Figure-8: Subsurface spall on an inner ring raceway

The bearing is damaged as soon as spalling occurs This does not mean that the bearing cannot remain in service Spalling gradually increases and gives rise to noise and vibration levels in the machine the machine should be stopped and repairedbefore the bearing collapses the period from initial spalling to failure depends on the type of machine and its operating conditions as shown in figure-7. The bearing ran a long time before the crack came to the surfaceThis typically occurs in bearings made of very clean steel running under clean and well lubricated operating conditions Notice the flat bottom of the spalled area and the “neat” cracks around it These are cracks that have come to the surface and in time, more material will break away as shown in Figure-8.

B. Surface initiated fatigue

Surface initiated fatigue basically comes from damage to the rolling contact surface asperities, which is generally caused by inadequate lubrication Inadequate lubrication can be caused by a number of different factors If the surface is damaged, for instance by the over-rolling of solid contaminants, lubrication is no longer optimal and the lubricant film is reduced or becomes inadequate This can also occur if the amount or type of lubricant is not appropriate for the application and the contact surfaces are not adequately separated The resulting metal-to-metal contact causes the surface asperities to shear over each other, which together with microslip between the rolling contact area surfaces, creates a burnished or glazed surface Thereafter, microcracks may occur at the asperities, followed by microspalls, finally leading to surface initiatedfatigue There is a risk of surface-initiated fatigue in all bearings if the oil film does not fully separate the rolling contact surfaces.The risk increases if there is sliding in the rolling contact area All rolling bearings show some microslip (also called micro sliding) in the rolling contact area due to their specific geometry and elastic deformation of the rolling elements and raceways under load.

Generally, these microspalls are only a few microns in size and the surface just looks dull and grey as shown in figure-9, Only under a micro-scope can cracks and spalls be detected (Figure-10).



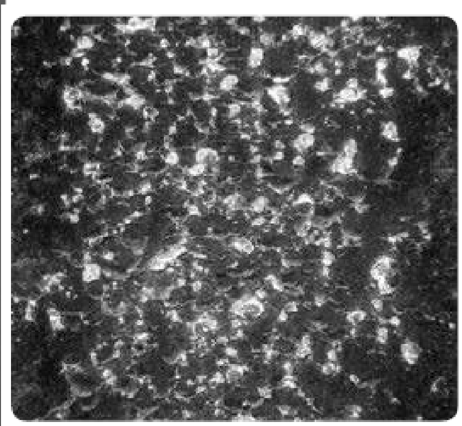


Figure-9: Microspalls on the inner ring raceways of a spherical roller bearing Figure-10: Microspalls and cracks on the raceway surface

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V. WEAR

A. Abrasive Wear

Abrasive wear means progressive removal of material Initially, a bearing experiences some very light wear during the running-in stage, mostly just showing a path pattern.

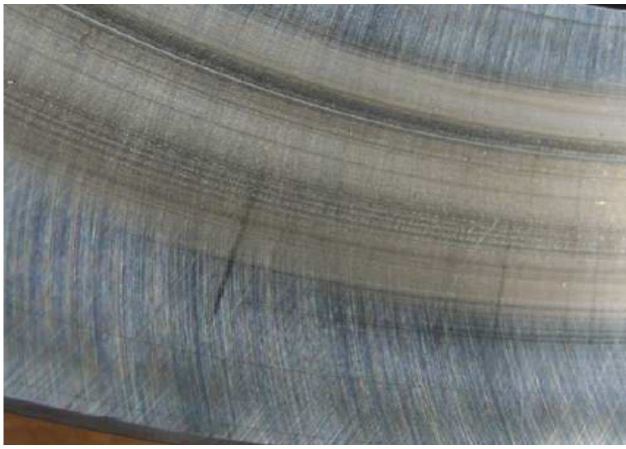

Figure-11: Light abrasive wear on the outer ring

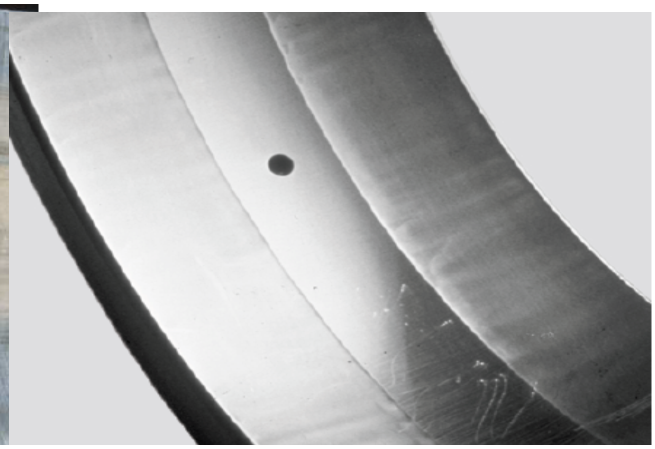

Figure-12: Advanced abrasive wear on the outer ring

As shown in Figure-11 Initially, a bearing experiences some very light wear during the running-in stage, mostly just showing a path pattern, Most of the time, real abrasive wearoccurs due to inadequate lubrication or theingress of solid contaminants Abrasive wearis generally characterized by dull surfaces (Figure-12). Abrasive wear is a degenerative processthat eventually destroys the microgeometryof a bearing because wear particles furtherreduce the lubricant's effectiveness Abrasiveparticles can quickly wear down the racewaysof rings and rolling elements, as wellas cage pockets Fig. 12 shows abrasivewear on the outer ring of a rollerbearing.

B. Adhesive Wear

Adhesive wear is a type of lubricant-related damage that occurs between two mating surfaces sliding relative to eachother,This is also known as Smearing, It is characterized by the transfer of material from one surface to another (smearing) It is typically accompanied by frictional heat, which can sometimes temper or reharden the mating surfaces ,The frictional heat produces local stress concentrations, which can cause cracking or spalling in the contact areas, Smearing is not common under normal operating conditions the relative sliding speed must be much higher than the microslip induced by the bearing geometry and elastic deformation in the rolling contact area.

Smearing (adhesive wear) Figure-12 due to severe accelerations Under certain conditions, smearing can occur on the surface of the rolling elementsand in the raceways of rolling bearings operatingat relatively high speeds Outside the load zone, the rolling element rotation is retarded because the rings do not drive the rolling elements

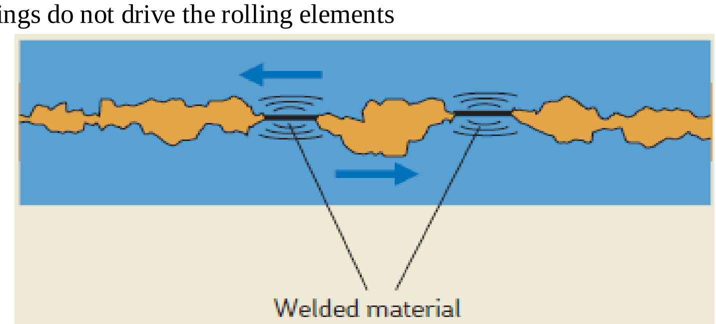

Figure-12: Principle of adhesive wear

The phenomenon of smearing is also called galling or scuffing Smearing is a dangerous type of surface damage because the surfaces affected normally become progressively rougher As surface roughness increases, the oil film thickness decreases, which increases metal-to-metal contact and bearing wear enters a vicious cycle Large bearings are quite sensitive to smearing

The weight of the rolling elements becomes important and they slowdown considerably outside the load zone When re-entering the load zone they are almost instantly accelerated to the rotational speed, but due to the rolling element weight it occurs with (partial) sliding.

Smearing due to gyroscopic effects also occurs in ball bearings In these cases, the balls change their contact angle when they are outside the load zone but are forced back (with slip) to their correct contact angle as they enter the load zone Smearing (adhesive wear) due to too light loading Smearing can also occur between rolling elements and raceways when the load is too light relative to the speed of rotationWays to overcome mearing include, butare not limited to:

- Increasing the load
- Using smaller bearings
- Using hybrid bearings (lighter rollingelements)
- Applying protective coatings
- Using a different cage execution
- Reviewing oil/grease selection

Figure-13: Smearing on a rollerthrust face of aspherical roller thrust bearing

Smearing can also occur between the cageand its contact surface and between theroller ends and guide flanges Fig. 13 showsa roller from a spherical roller thrust bearingthat was riding against the guide flange theroller end has smearing damage caused byinadequate lubrication.

VI. COROSSION

A. Moisture Corrosion

Ineffective sealing arrangements can allow moisture, water and aggressive liquid contaminants to enter the bearing When the quantity of liquid contaminants exceeds the ability of the lubricant to adequately protect the steel surfaces, rust will form.

1) Oxidation

A thin protective oxide film is formed on clean steel whose surfaces are exposed to air However, this film is not impenetrable and if water or corrosive agents make contact with the steel surfaces, oxidation will occur.

2) Corrosion

Corrosion is perhaps the most common cause of premature bearing failure in paper machines and process equipment in the food and beverage industries Bearings in these machines are exposed to the ingress of water and other liquids as part of the operational process Water can also be introduced during washdowns while the machine is being cleaned at standstill, resulting in greyish-black patches coinciding with the rolling element patches shown in figure-14.

3) Etching

At standstill, free water in the lubricant willaccumulate at the bottom of the bearingThe water concentration will be highest at a certain distance from the rolling contact as shown in fig-15 The reason is that the freewater is heavier than the oil and will sinkuntil it comes to a suitable gap between therolling element and the raceway This canlead to deep-seated corrosion, called etching as shown in fig-16.

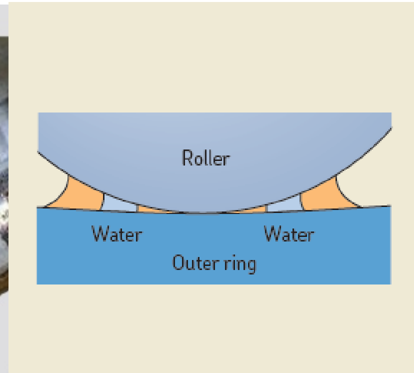

Figure-14: Corrosion on Outer ring

Figure-15: Free water in the lubricantaccumulates at thebottom of the

Figure-16: Initial patches of etching at rolling elementpitch

Etching usually leads to premature, extended spalling as the material is subjected to a structural change and the surfaces in the load zone are reduced to such an extent that overloading occurs The best way to avoid corrosion is to keep the lubricant free from water and aggressive liquids by adequately sealing the application Using a lubricant with good rust-inhibiting properties also helps.

B. Frictional Corrosion

1) Fretting corrosion

Fretting corrosion occurs when there is relative movement between a bearing ring and its seat on a shaft or in a housing Fretting is usually caused by a too loose fit or form inaccuracies, The relative movement may cause small particles of material to become detached from the bearing surface and its seat These particles oxidize quickly when exposed to air and the result is iron oxide as shown in figure-17.

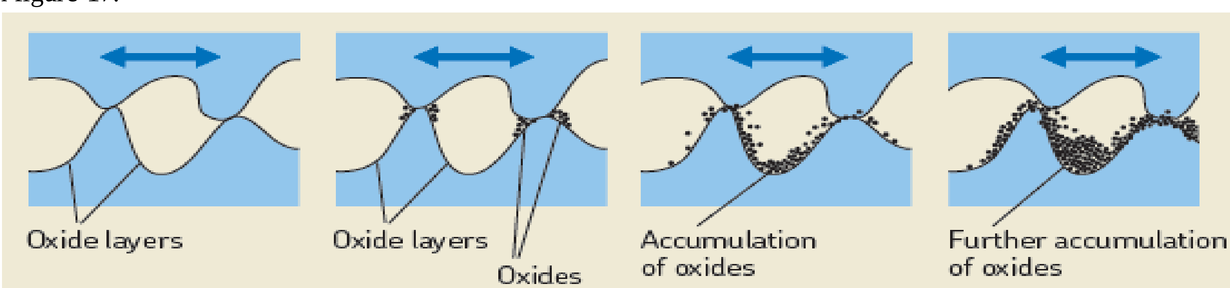

Figure-17: Schematic view of different stages indevelopment of fretting corrosion

Iron oxide is larger in volume than iron (steel) As a result of the fretting corrosion, the bearing rings may not be evenly supported, which can have a detrimental effect on the load distribution in the bearing Corroded areas also act as fracture notches Depending on the chemical reaction, corrosion could appear as:

- red (hematite, Fe_2O_3)
- black (magnetite, Fe_3O_4)

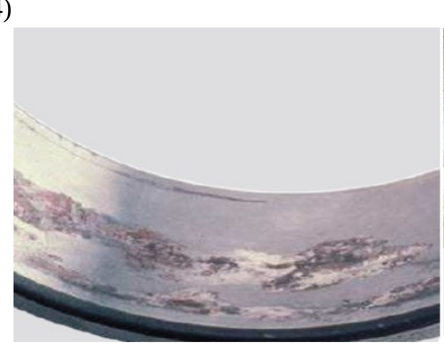

Figure-18: Fretting corrosion on an inner ring due to inadequate shaft seat orshaft bending Figure-19: Fretting corrosion on an inner ring bore resultingfrom heavy load or inadequate shaft seat

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Fretting corrosion resulting from a shaft surface that was not properly machined or from shaft bending (due to a cantilever load or an overhung load) as shown in Fig-18.

Fretting corrosion from very heavy loading or an inadequate seat To avoid fretting corrosion or to slow the process, either the tolerances (fit) should be adjusted, or a special anti-fretting paste or coating should be applied as shown in Fig-19.

2) False brinelling

False brinelling occurs in the contact area due to micromovements and/or resilience of the elastic contact under cyclic vibrations Depending on the intensity of the vibrations, lubrication conditions and load, a combination of corrosion and wear can occur, forming shallow depressions in the raceway In the case of a stationary bearing, the depressions appear at rolling element pitch:

• Sphered depressions for ball bearings
• Longitudinal depressions for rollerbearings

False brinelling in grease lubricated applications is typically a reddish-brown, while very shiny mirror-like depressions appear in oil lubricated applications, severe false brinellingdamage caused to the outer ring of a self-aligningball bearing at standstill as shown in Fig-20

Figure-20: Severe false brinelling on the outer ringraceway of a self-aligning ball bearing

Figure-21: False brinelling ("flutes") on the outer ring raceway

false brinelling damage on the outer ring of a cylindrical roller bearing, The root cause is vibration during standstill the bearing was mounted in auxiliary equipment, with long standstill periods Several sets of "flutes" can be observed at roller pitch, each set resulting from a period of standstill The magnitude of damage depends on the level of vibration, frequency of vibration, and length of standstill as shown in Fig-21.

VII.ELECTRICAL EROSION

A. Excessive current erosion

When an electric current passesfrom one ring to the other via the rollingelements, damage will occur as shown in Fig-22 At thecontact surfaces, the process is similar toelectric arc welding (high current densityover a small contact surface,) The materialis heated to temperatures ranging fromtempering to melting levels This leads to theappearance of discoloured areas, varying insize, where the material has been tempered,rehardened or melted Craters also formwhere the material has melted and consequently,broken away due to the rotation ofthe rolling element.

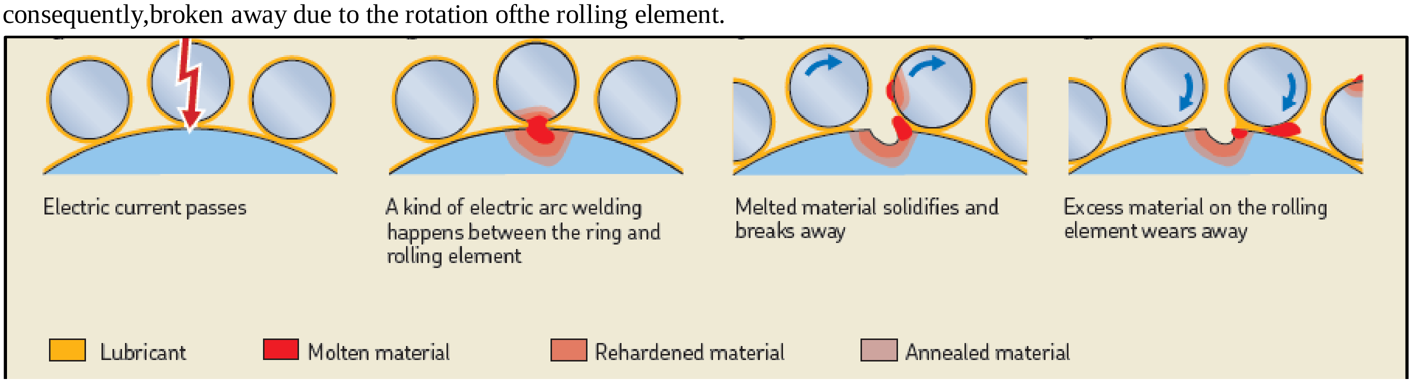

Figure-22: Mechanism of excessive current erosion

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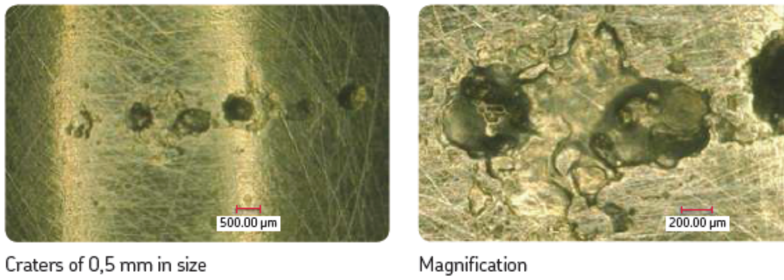
The excess materialon the rolling element wears away Appearance: Craters in raceways and rollingelements Sometimes zigzag burns can beseen in ball bearing raceways Local burnsare visible on the raceways and rollingelements.



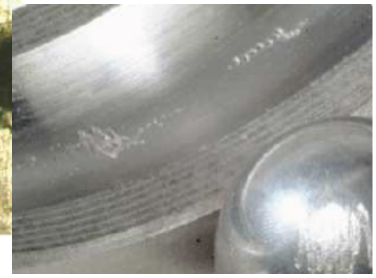


Figure-23: Excessive current erosion on the bearing roller   Figure-24:Excessive current erosion onthe outer ring raceway and ball

Spherical roller bearing subjected to an excessive electrical current A number of rather large craters can be seen on the roller A magnification clearly shows the craters with the molten material around their edges as Shown in Fig-23.
Another example of damage caused by excessiveelectrical current in a deep groove ballbearing, both on the outer ring raceway andball Notice the zigzag burns as sown in Fig-24.

B. Current leakage erosion

In the initial stage of current leakage erosiondamage, the surface is typically damaged byshallow craters that are closely positioned toone another and smaller in diameter comparedto the damage from excessive currentThis happens even if the intensity ofthe current is comparatively low.

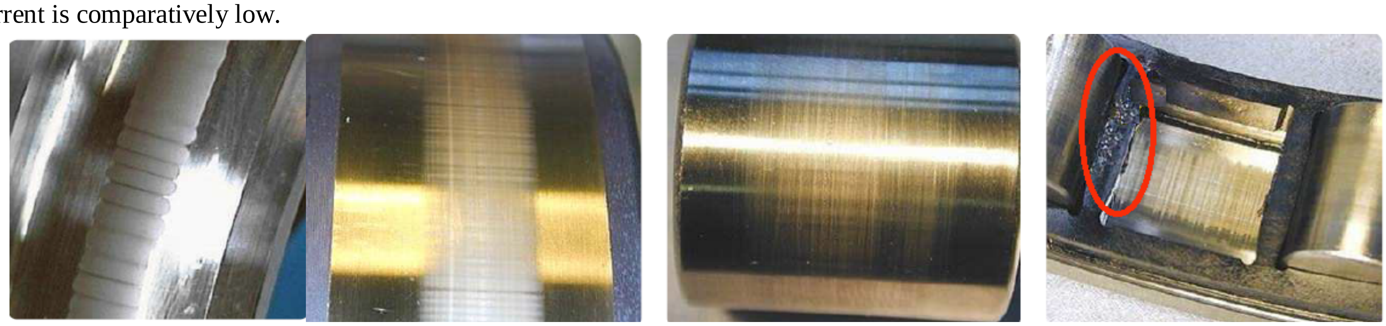


Figure-24:Washboarding caused by current leakage erosion

A washboard pattern may develop fromcraters over time the pattern appears onthe raceways Fig-24 For rollerbearings, the washboard pattern alsoappears on the rollers as shown in Fig-24 In ballbearings, the balls typically become discoloured (dull, light to dark grey) over their entiresurface.The extent of the damage depends on anumber of factors: current intensity, duration, bearing load, speed and lubricant. This also shows in cylindricalroller bearing due to current leakage Washboardingis developing on the raceways androllers Notice the grease on the cage pocketsat the start of this failure mode, the greaseis gradually carbonized and loses its abilityto form a lubricant film This eventually leadsto surface initiated fatigue, spalling and evensudden seizure.

VIII. PLASTIC DEFORMATION

A. Overload Deformation

Overload deformation can be caused by static overloading, shock loads or improper handling in any of these cases, the resulting damage looks the same, which is why they are combined into one failure sub-mode.
For Example, in Figure-25 where a cage was hit directly, causing it to deform If this bearing were put into operation, high noise and vibration levels would result, As shown in Figure-26 Raceways and rolling elements may becomedented if the mounting force is appliedthrough the rolling elements, orif the bearing is subjected to abnormal loadingwhile stationary The distance betweenthe indentations is at rolling element pitch, as shown in Figure-27.

Figure-25:Plastic deformation on the cage of bearing due to poor handling

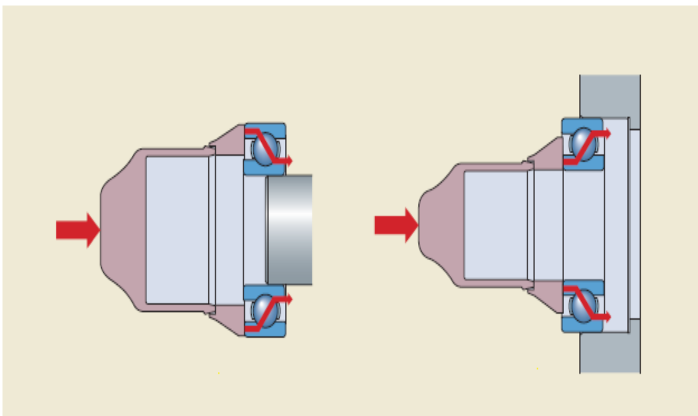


Figure-26:Overload deformation resulting from an incorrect mounting method   Figure-27:Indentations at ball pitch on the raceway

Always use the correct mounting tools and methods as shown in Figure-28, Handling is critical during manufacturing, transport, storage and mounting Poor handling is characterized by local overloading and visible "nicks" caused by hard and/or sharp objects Fig. 29 shows an example of poor assembly of a cylindrical roller bearing in the mounting stage The rollers have made nicks on the inner ring raceway at roller pitch If put into service, high noise and vibration levels will result.

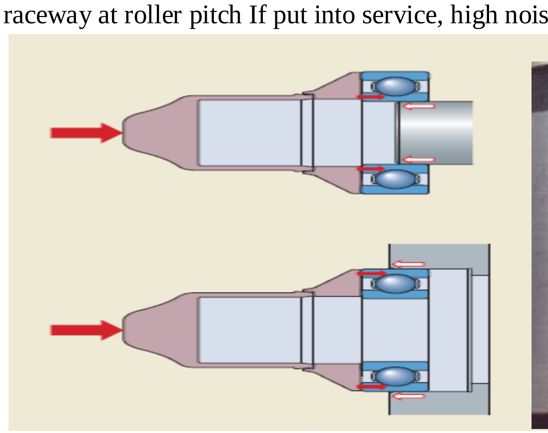


Figure-28:Correct Mounting

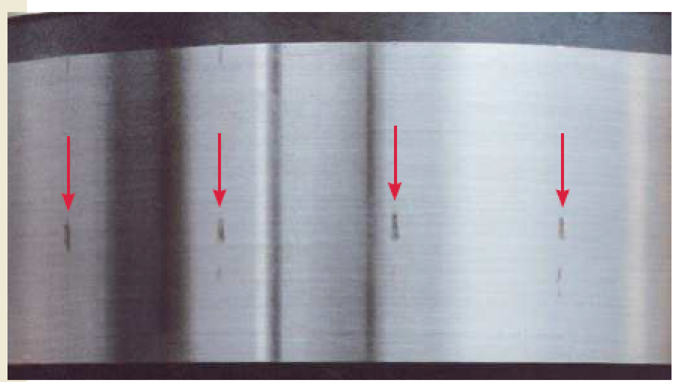


Figure-29:Inner ring of a bearing with nicks that occurred duringmounting

B. Indentations from debris

Solid contaminants can be introduced into a bearing via the seals or lubricant They can also be the result of wear or damage to an adjacent component, such as a gear When a solid contaminant is over-rolled by the rolling elements, it is pushed into the raceway and causes an indentation The particle producing the indentation need not be hard Even rather soft particles, when big enough, can be harmful Raised material around the edges of an indentation initiate fatigue When the fatigue level reaches a certain point, it leads to premature spalling, originating at the back end of the indentation (fig. 30) The spall starts as a surface crack

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The most important operating data required for the calculation are the bearing type and size, rotational speed, bearing load, viscosity ratio, and the size, hardness and concentration of the contamination particles, Lubricant cleanliness and careful handling during mounting are important factors in the prevention of indentations Fig. 31 shows spalling in a deep groove ball bearing, resulting from an indentation The over-rolling direction is from bottom to top The V-shape is a typical sign of indentation damage in a bearing where the initial spalling opens up from the back end of the indentation, Fig. 32clearly shows the consequences of indentations (spherical roller bearing inner ring) The over-rolling direction is from right to left A rather large and soft contaminant was trapped in the raceway and overrolled At the bottom of the dent, grinding lines are still visible Also notice the raised rim around the dent To the left, behind the dent, there is a large spall (black colour) where material has been detached There are also some cracks, where the material is about to be detached.

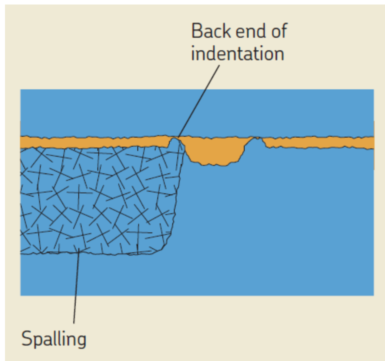

Figure-30:Spalling starting at the back end of anindentation

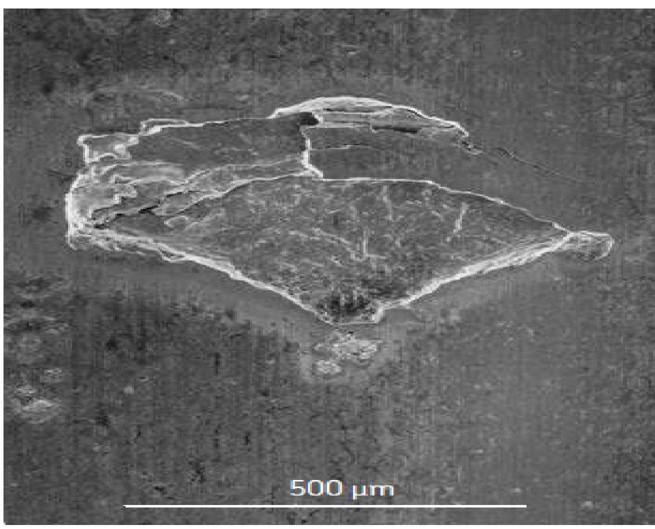

Figure-31:Spalling resulting from an indentation in theinner ring of a bearing


Figure-32:Spalling resulting from an indentation in a bearing

IX. FRACTURE AND CRACKING

A. *Forced Fracture*

A forced fracture results when stress concentrations exceed the tensile strength of the material Local overloading and overstressing are two common causes of a forced fracture, As shown in Fig. 33 shows rough treatment, a common cause for fracture It happens when bearings are mounted cold, with a hammer and chisel Hitting the ring directly can cause fine cracks to develop, which will quickly turn into through-cracks when the bearing is put into operation.

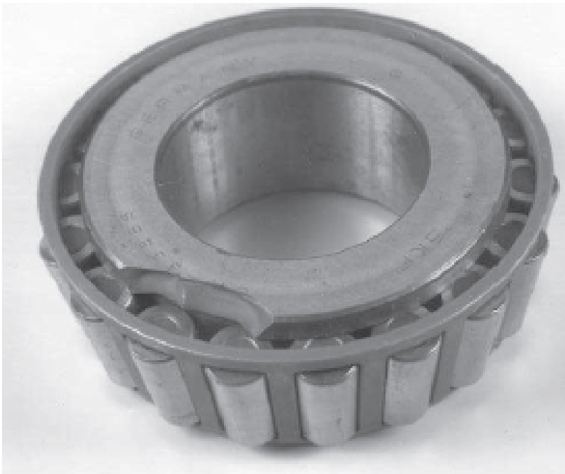

Figure-33:Fracture on the large shoulder of a tapered roller bearing inner ringresulting from rough treatment

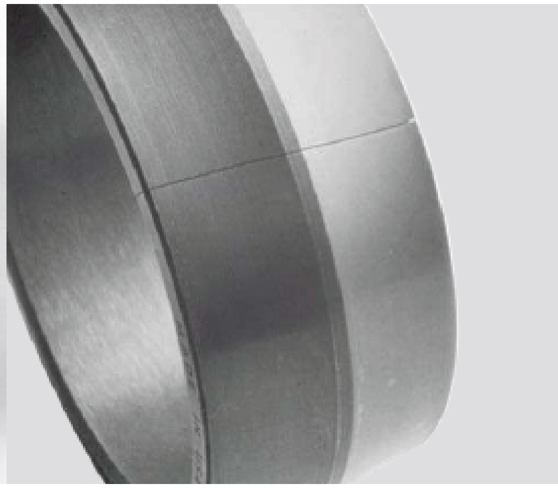

Figure-34:Fractured inner ring of a spherical roller bearing with a tapered boreresulting from excessive drive-up

Excessive drive-up (fig. 34) on a tapered seat can cause an inner ring to fracture, The hoop (tensile) stresses, arising in the ring as a result of excessive drive-up, cause the ring to crack through in service Martensite hardened rings are more sensitive to this than bainite hardened rings The same result may occur when bearings are heated and mounted on oversized shafts.

B. Fatigue Fracture

A fatigue fracture starts when the fatigue strength of a material is exceeded under cyclic bending Repeated bending causes a hairline crack which propagates until the ring or cage develops a through crack Fig. 35 shows an example of a cracked outer ring of a spherical roller bearing The bearing was mounted in a housing with insufficient support in the load zone As a result, the bearing outer ring was subjected to cyclical bending stress, until the ring developed a through crack.

Figure-35:Fatigue fracture of an outer ring of a spherical roller bearing

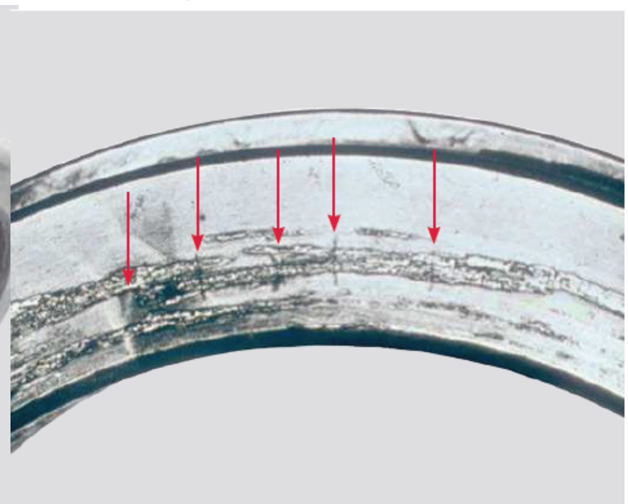

Figure-36:Transverse thermal cracks on the small side face of the inner ring of atapered roller bearing

C. Thermal Cracking

Two surfaces sliding against each other generate frictional heat If the sliding is substantial, the heat can cause cracks, which are generally at right angles to the direction of the sliding, A typical example is shown in fig. 36, A rotating inner ring was fitted with a loose fit and subjected to an axial load Due to creep, there was a sliding movement between the bearing side face and the shaft shoulder or spacer, which resulted in smearing The frictional heat results in transverse cracks and eventually the ring will crack through.

X. CONCLUSIONS

Bearings play a critical role in ensuring the reliable and efficient operation of rotating machinery across diverse industrial sectors. This paper has systematically examined the predominant bearing failure modesfatigue, wear, corrosion, plastic deformation, and fractureproviding detailed insights into their root causes, including improper lubrication, contamination, misalignment, overloading, and inadequate installation. By elucidating the characteristic features and underlying mechanisms of each failure type, the study emphasizes the significance of accurate life prediction models, particularly the bearing life rating formula, in shaping effective maintenance strategies. A comprehensive understanding of how damage initiates and progresses enables engineers and maintenance professionals to implement targeted preventive measures, optimize maintenance schedules, and minimize unscheduled downtime. Ultimately, enhancing bearing reliability not only improves machinery performance and safety but also extends service life, contributing to cost savings and operational efficiency. Future research should focus on advanced diagnostic techniques and predictive maintenance technologies to further advance the reliability engineering of bearings in increasingly complex mechanical systems.

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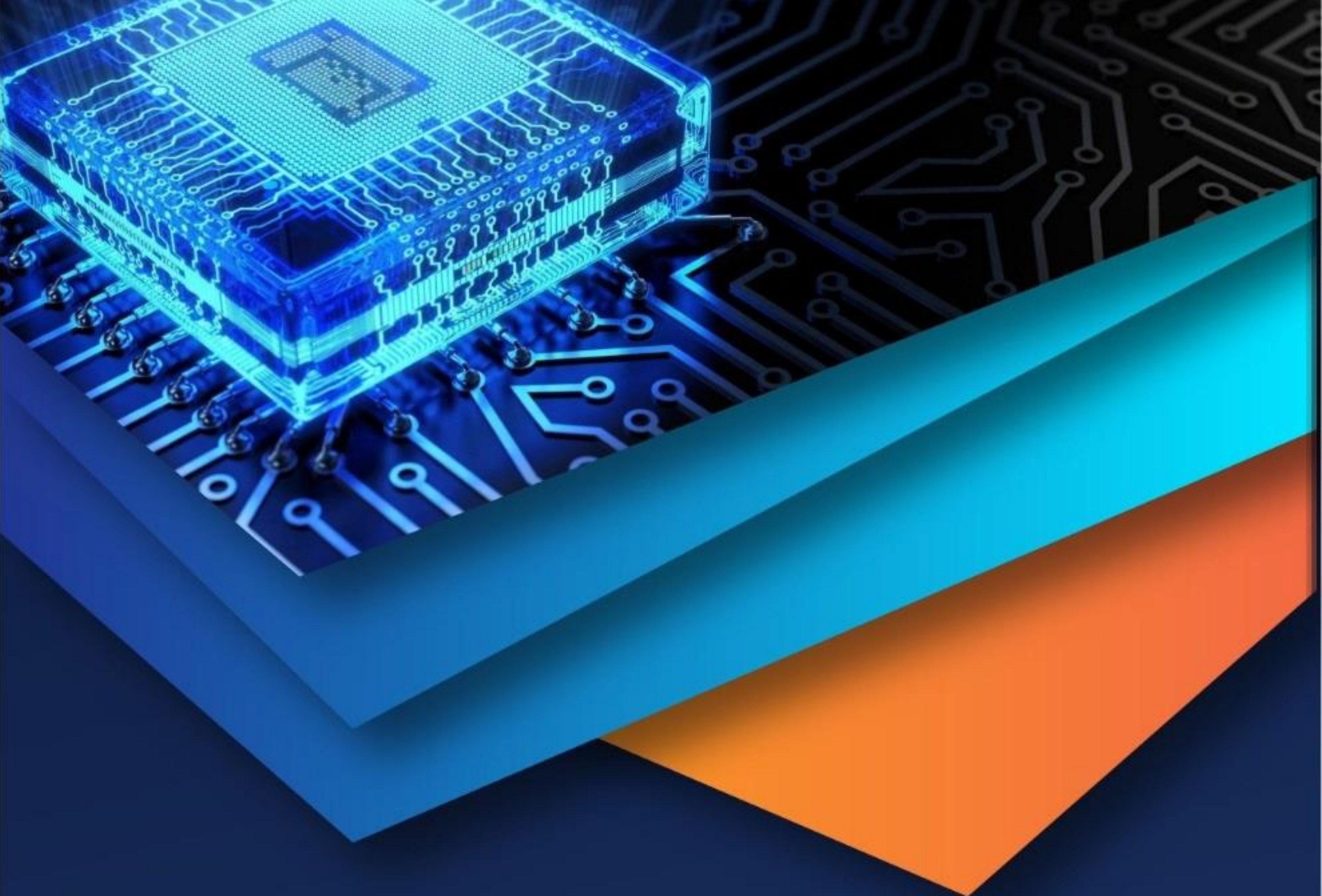
[3] SKF Literature for bearing reliability and failure prevention.
[4] ARB Bearings technical catalogue.,
[5] Reliability Engineering technical literature.
[6] Training literature of Advancement of bearing technology by Mr. Sushil Sharma.
[7] SKF bearing technical document.



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