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Failure Mode and Effect Analysis of Journal Bearing

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Abstract- In the present research work the Failure Mode and Effect Analysis (FMEA) of a conventional radial journal bearing is presented. The FMEA process is applied to identify the various possible failures modes of a journal bearing and the corresponding effects of these failures on the bearing performance. The severity, occurrence and detection of the failures modes are determined based on a rating scale of 1 to 10 to quantify the relative risk of a failure and its effects on the bearing performance. The Risk Priority Number (RPN) of the failure mode is quantified and it is utilized in ranking the failure. The methods to eliminate or reduce the high-risk failure modes are proposed and experimental investigations are conducted to validate the proposed solutions.

Keywords: Risk priority number, Friction, Abrasive Wear, Adhesive Wear, plastic deformation, Indentation of bearing, Non-uniform wear.

Introduction

An FMEA (Failure Mode and Effect Analysis) is a systematic method of identifying and preventing product and process problems before they occur. FMEAs are focused on preventing defects, enhancing safety, and increasing customer satisfaction. Ideally, FMEA is conducted in the product design stage, although conducting an FMEA on existing products can also yield substantial benefits [1].

The ISO/TS 16949 standard requires that suppliers to industry conduct product/design and process FMEAs in an effort to prevent failures before they happen. The FMEA is a well established quality improvement tool that yield significant savings for a company while at the same time reducing the potential costly liability of a product that does not perform as specified. FMEAs do take time and people resources. Because FMEAs are team based, several people need to be involved in the process. The foundation of FMEAs is the FMEA team members and their input during the FMEA process [1].

The main objective of an FMEA process is to identify all the potential modes of failure of a product. The failure of a product failure is said to occur when it does not function as per the requirements or when the product does not fulfill the required performance objectives. Even though the designer ensures that the product satisfies all requirements but in spite of all precautions there are several situations that cause product failure. Each identifiable and distinguishable manner in which a product may fail is known as its failure mode. Each failure mode affects the product performance, safety, economy, reliability and has a potential to result into a catastrophic failure. Therefore, each potential effect has a relative risk associated with it. The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them [1].

The relative risk of a failure and its effects is determined by three factors: **Severity**—The consequence of the failure should it occur, **Occurrence**—The probability or frequency of the failure occurring, **Detection**—The probability of the failure being detected before the impact of the effect is realized [1].

The product FMEAs may be carried out in any of the phases in the design process, however, the essential steps shown in figure 1are required.

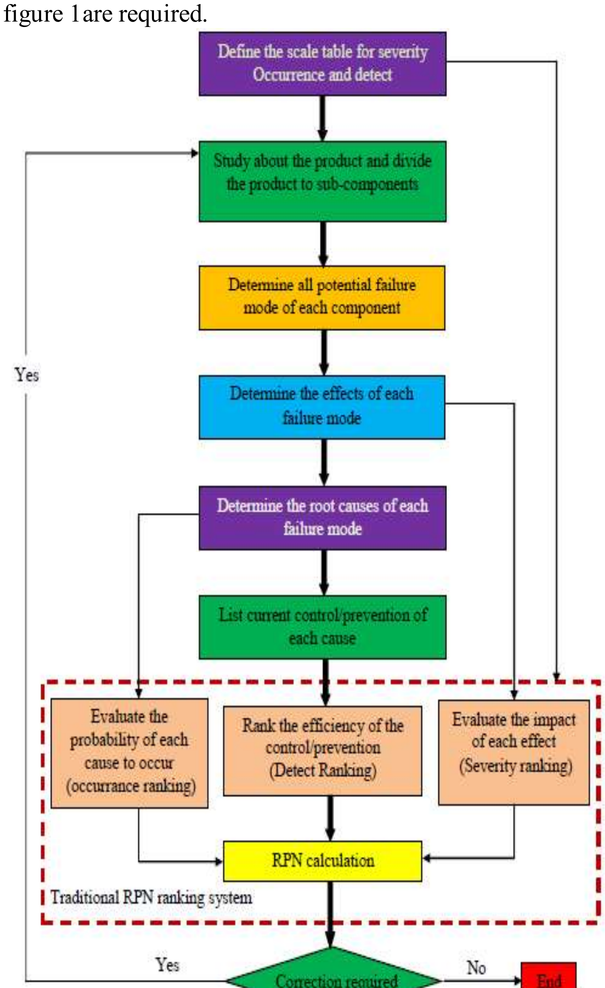

Figure 1 Traditional FEMA process

Step 1 Review the product.
The engineering drawings and 3D models of the product should be reviewed to understand the product. The interrelationship between various assemblies of the system must also be ascertained. The journal bearing system (figure 2), which is the product of the present study, consists of a journal made of steel that rotates in a bearing made of softer material. The journal is subjected to the external loads like torque and loads. The members that may be attached to the journal include gears, pulleys, disks etc. In the present research work, the lubricant supply system is considered as a sub-system and no further sub-components of the system are considered.

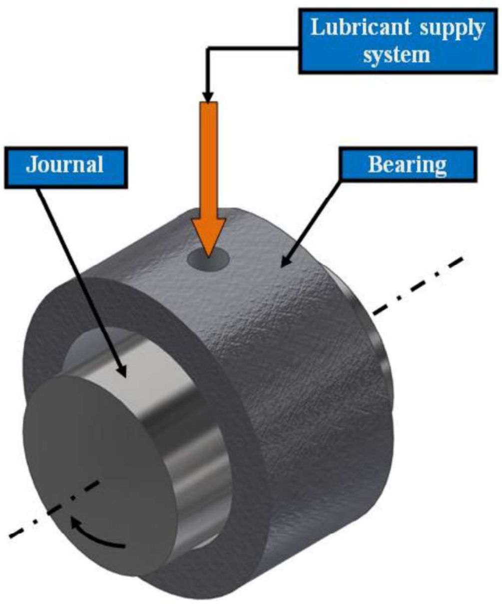

Figure 2 Schematic diagram of Journal bearing with lubricant supply system

The bearing is generally considered as a sacrificial element in the journal bearing system. The sectional view of the bearing is shown in figure 3.

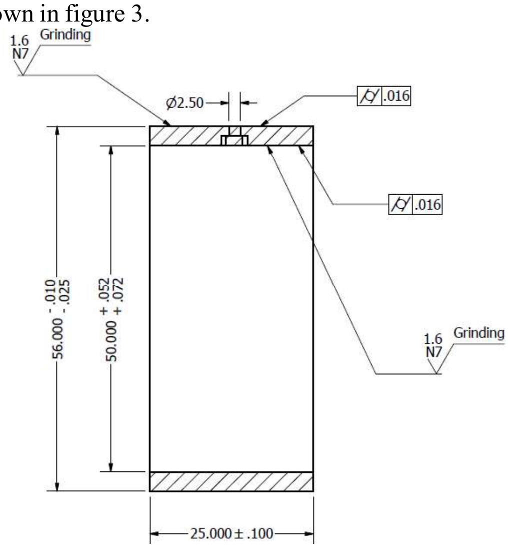

Figure 3 Sectional view of bearing with geometric dimensions and tolerances (All dimensions in mm)

Step 2 Brainstorm potential failure modes.
Identify potential failure modes that could affect the product performance. Focusing on the elements one at a time will result in a more thorough list of potential failure modes. The ideas should be organized by grouping them into like categories. When the failure modes have been grouped and combined, if appropriate, they should be transferred onto the FMEA sheet. Note that there are usually several failure modes for each component. In the case of journal bearing, failures related to journal, bearing, lubrication system and lubricant are considered.
The journal may fail due to Abrasive wear; Adhesive wear; Subsurface fatigue; Surface fatigue; Moisture corrosion; Frictional corrosion; Plastic deformation; Indentation; Fatigue fracture; Thermal cracking; Improper geometry of the journal due to manufacturing inaccuracies; Non-uniform wear causing geometrical variations that deteriorates performance; etc. The figure 4(a) and 4(b) depicts a new journal and a fractured journal respectively.

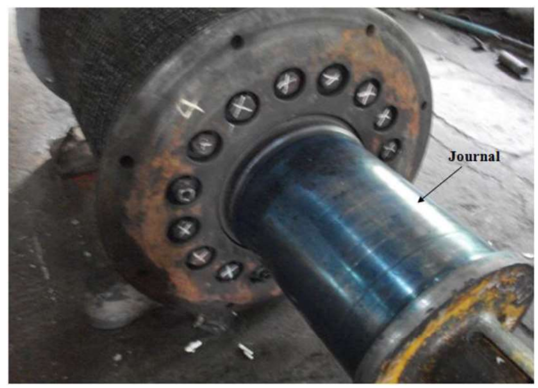

Figure 4(a) New journal fitted to the crushing roller [14]

Figure 4 (b) Fractured journal

The bearing may fail due to improper geometry of the bearing due to manufacturing inaccuracies; non-uniform wear causing geometrical variations that deteriorates performance; embedding of hard foreign particles; Spalling; Abrasive wear; Adhesive wear; Subsurface fatigue; Surface initiated fatigue; Moisture corrosion; Frictional corrosion; Plastic deformation; Indentation; Fatigue fracture; Thermal cracking; Fretting; True brinelling; False brinelling; Smearing; etc. The figure 5(a) to 5(e) depicts worn out/failed bearings.

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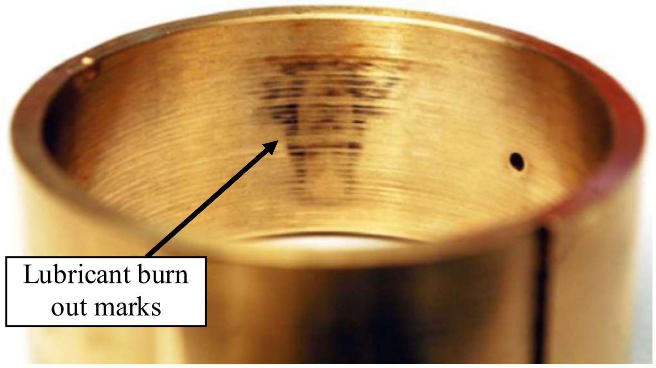

Figure 5 (a) Lubricant burnout marks

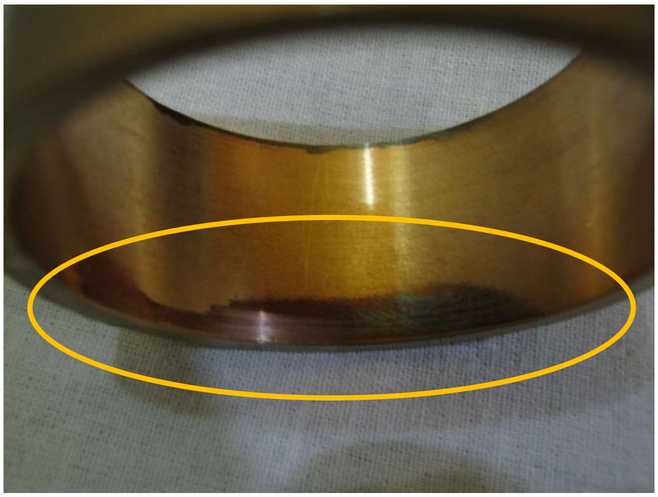

Figure 5 (b) Wear at the side due to edge loading

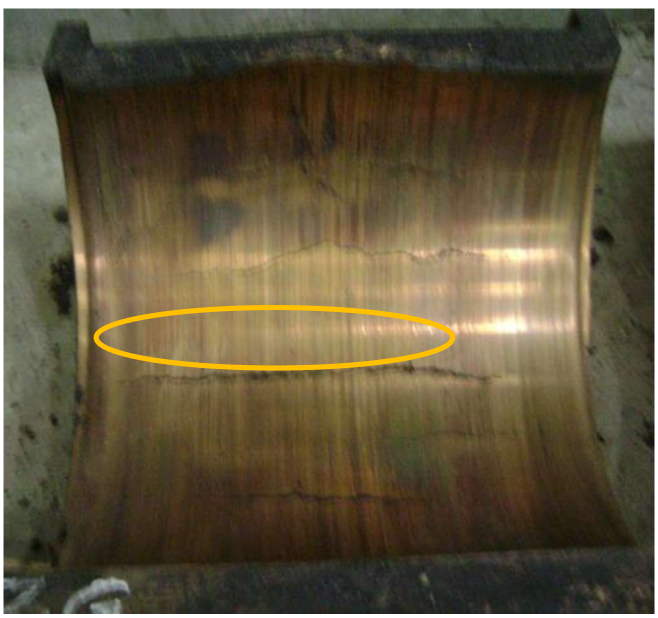

Figure 5 (c) Surface cracks

The lubrication system may fail due to lubricant leakage; partial supply of the lubricant; lubricant supply without filtration of debris; Supply of lubricant at an undesirable temperature; Supply of lubricant with other contaminants; etc.

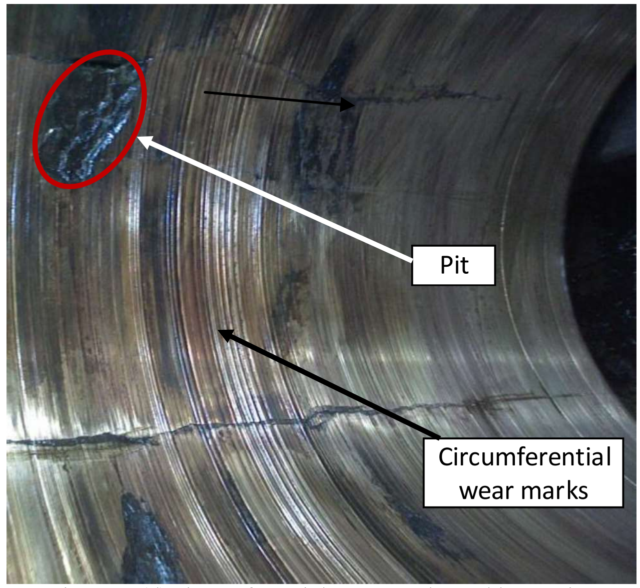

Figure 5 (d) circumferential wear marks and large pits

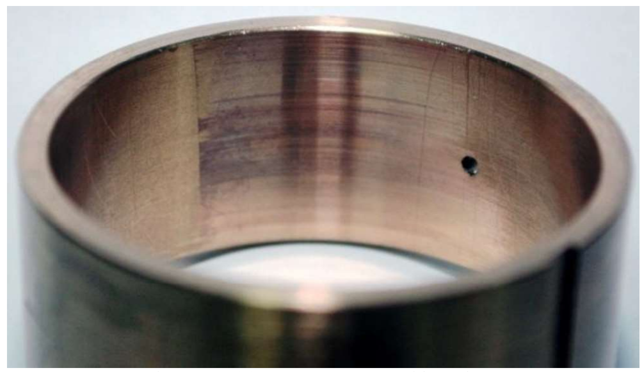

Figure 5 (e) Severe wear of bearing

The lubricant may fail due to Moisture contamination; oxidation; depletion of lubricant additives; improper viscosity of the lubricant; undesired operating temperature; etc. In addition, failures due to connected elements occurs due to unbalance rotating masses; loose rotating parts; excessive preload; misalignment; looseness; excessive overload; seal leaks; etc.

Step 3 List potential effects of each failure mode.

After the identification of all the failure modes of the journal bearing system, each failure mode is reviewed and its effect on the performance is determined. This also requires identification of severity of each mode of failure. Each failure mode may have one or more potential effects that need to be identified. This step is an important step as it will later reflect on the importance of each failure mode, therefore it must be carried out meticulously. This step is similar to an if-then process: *If* the failure occurs, *then* what are the consequences?

Step 4 Assign a severity ranking for each effect.

The severity ranking is an estimation of how serious the effects would be if a given failure did occur. In some cases it is clear, because of past experience, how serious the problem would be. In other cases, it is necessary to estimate the severity based on the knowledge and expertise of the team members.

Table 1 Severity guidelines for journal bearing FMEA (1-10 qualitative scale)

Effect	Rank	Criteria
No	1	No effect on bearing performance.
Very Slight	2	Very slight increase in friction only.
Slight	3	Slight increase in friction only.
Minor	4	Minor increase in friction only.
Moderate	5	Moderate increase in friction only.
Significant	6	Increase in friction and slight wear occurrence.
Major	7	Significant increase in friction and moderate wear occurrence.
Extreme	8	Significant increase in friction and wear.
Serious	9	Complete failure of lubrication with maximum increase in friction and wear.
Hazardous	10	Catastrophic failure.

Step 5 Assign an occurrence ranking for each failure mode.

The best method for determining the occurrence ranking is to use actual data from the process. This may be in the form of failure logs or even process capability data. When actual failure data are not available, the team must estimate how often a failure mode may occur. The team can make a better estimate of how likely a failure mode is to occur and at what frequency by knowing the potential cause of failure. Once the potential causes have been identified for all of the failure modes, an occurrence ranking can be assigned even if failure data do not exist.

Table 2 Occurrence guidelines for journal bearing FMEA (1-10 qualitative scale)

Effect	Rank	Criteria
Almost Never	1	Failure unlikely. History shows no failure
Remote	2	Rare number of failures likely.
Very Slight	3	Very few failures likely.
Slight	4	Few failures likely.
Low	5	Occasional number of failures likely.
Medium	6	Medium number of failures likely.
Moderately High	7	Moderately high number of failures likely.
High	8	High number of failures likely.
Very High	9	Very high number of failures likely.
Almost certain	10	Failure almost certain.

Step 6 Assign a detection ranking for each failure mode and/or effect.

Assign rankings based on a 10-point scale, with 1 being the lowest ranking and 10 the highest.

Table 3 Detectability guidelines for journal bearing FMEA (1-10 qualitative scale)

Effect	Rank	Criteria
Almost certain	1	Proven detection methods available in concept stage.
Very High	2	Proven computer analysis available in early design stage.
High	3	Simulation and/or modelling early stage.
Moderately High	4	Tests on early prototype system elements.
Medium	5	Tests on preproduction system components.
Low	6	Tests on similar system component.
Slight	7	Tests on product with prototype and system components installed.
Very Slight	8	Proving durability tests on product with system components installed.
Remote	9	Only unproven or unreliable technique(s) available.
Almost impossible	10	No known techniques available

Step 7 Calculate the risk priority number for each effect.

The risk priority number (RPN) is calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item.

Risk Priority Number = Severity × Occurrence × Detection

The total risk priority number is calculated by adding all of the risk priority numbers.

Step 8 Prioritize the failure modes for action.

The failure modes can now be prioritized by ranking them in order, from the highest risk priority number to the lowest.

Step 9 Take actions to eliminate or reduce the high-risk failure modes.

Identify and implement actions to eliminate or reduce the high-risk failure modes. Ideally, the failure modes should be eliminated completely. When a failure mode has been eliminated completely, the new risk priority number approaches zero because the occurrence ranking becomes one. While elimination of failure modes altogether is ideal, it may not be achievable in all cases. When this happens, it helps to refer back to the severity, occurrence, and detection rankings that the team assigned to each item.

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Table 4 FMEA worksheet for Journal

A: Name of Component: Journal					
Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	RPN
Abrasive wear	Temperature rise of lubricant, decrease in lubricant viscosity, increase in friction and wear	4	3	1	12
Adhesive wear	Temperature rise of lubricant, decrease in lubricant viscosity, increase in friction and wear	4	4	1	16
Subsurface fatigue	Formation of subsurface cracks, increase in stresses due to stress concentration with consequent reduction in load carrying capacity	6	3	7	126
Surface initiated fatigue	Formation of pits on the surface, increase in friction and wear	6	3	7	126
Moisture corrosion	Lubricant contamination, increase in friction	7	3	1	21
Frictional corrosion	Surface damage in form of increased surface roughness	8	4	3	96
Plastic deformation	Change in journal surface profile, increases friction and wear	6	3	3	54
Indentation	Formation of uneven valleys deteriorating surface smoothness and increasing friction	8	4	4	128
Fatigue fracture	Journal failure, catastrophic failure	1 0	2	7	140
Thermal cracking	Reduction in load carrying capacity	9	2	4	72

Table 5 FMEA worksheet for bearing

B: Name of Component: Bearing					
Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	RPN
Non-uniform wear causing geometrical variations that deteriorates performance	Change in bearing surface profile, increase in friction and wear	7	8	4	224
Frictional corrosion	Surface damage in form of increased surface roughness	8	7	5	280

Table 5 FMEA worksheet for bearing (Continued)

B: Name of Component: Bearing					
Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	RPN
Adhesive wear	Temperature rise of lubricant, decrease in lubricant viscosity, increase in friction and wear	8	8	4	256
Improper geometry of the bearing due to manufacturin g inaccuracies	Non-uniform bearing surface profile, increase in friction and wear	8	8	4	256
Spalling		8	6	4	192
Abrasive wear	Temperature rise of lubricant, decrease in lubricant viscosity, increase in friction and wear	8	8	4	256
Subsurface fatigue	Formation of subsurface cracks, increase in stresses due to stress concentration with consequent reduction in load carrying capacity	8	3	7	168
Surface initiated fatigue	Formation of pits on the surface, increase in friction and wear	9	3	7	189
Moisture corrosion	Lubricant contamination, increase in friction	7	7	6	294
Plastic deformation	Change in bearing surface profile, increases friction and wear	8	6	6	288
Indentation	Formation of uneven valleys deteriorating surface smoothness and increasing friction	9	6	6	324
Fatigue fracture	Bearing fracture, catastrophic failure	8	3	6	144
Thermal cracking	Reduction in load carrying capacity	7	2	6	84
Fretting		7	2	6	84
True brinelling	Increased vibrations and noise, increased friction and wear	5	2	6	60
False brinelling	Increased vibrations and noise, increased friction and wear	5	2	6	60
Smearing	Increased friction, stiction	5	2	6	60

Table 6 FMEA worksheet for Lubrication system

C: Name of Component: Lubrication system					
Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	RPN
Fails to supply any lubricant to the bearing	Bearing seizure	10	5	1	50
Supply the lubricant only partially	Contact between journal and bearing, increased friction and wear	8	5	1	40
Supply lubricant without filtration of debris	Surface scratching, increase in friction and wear	8	5	1	40
Supply lubricant at an undesirable temperature	Undesirable lubricant viscosity, variation in frictional losses	7	5	1	35
Supply lubricant with other contaminants	Surface scratching, increase in friction and wear	7	5	1	35

Table 7 FMEA worksheet for other components

D: Name of Component: OTHERS					
Potential Failure Mode	Potential Effect(s) of Failure	Severity	Occurrence	Detection	RPN
Unbalance rotating masses	Increased friction and uneven wear	7	6	2	84
Cracked Shaft	Shaft fracture	9	3	7	189
Loose Rotating Parts	Vibration and noise	7	4	3	84
Misalignment	Increased friction and uneven wear	7	7	4	196
Lubricant Leakage	Lubrication starvation, temperature rise, contact between journal and bearing, increased friction and wear	8	4	3	96
Excessive overload	Metal fatigue	8	5	3	120
Seal Leaks	Lubrication starvation, contact occurs between journal and bearing, increased friction and wear	7	5	3	105

The major advantages of conducting an FMEA include the following:
• Improvement in the quality, reliability, and safety of the products.
• Facilitates selection of alternatives (in system, design, process, and service) with high reliability and high safety potential during the early phases.

Based on the FMEA sheet (Table 4, 5, 6, and 7) for the journal bearing, it is observed that wear is the predominant mode of failure of the bearing. The main feature of a failure is its detect-ability. Since it is difficult to take preventive measures for failures that are difficult to detect, therefore, it increases the probability of failure. The journal failure and lubrication system failure do not pose serious threat to the bearing performance as they are easily detectible and preventive measures may be taken accordingly. This is essentially true as the bearing is designed to be a sacrificial element of the journal bearing system. The wear of the bearing can be prevented by using suitable anti-wear lubricant additives, by providing grooving arrangement etc. The bearing geometry at the contact zone needs to be very precise for achieving minimum wear.

Conclusion

The failure mode and effect analysis for a journal bearing has been carried out. Forty possible modes of failure of a journal bearing system have been identified. The severity, occurrence and detection of these failures modes are utilized in quantifying the Risk Priority Number (RPN). The failure modes that are most critical are identified to be: wear (Abrasive and adhesive), plastic deformation and indentation of the bearing, non-uniform wear causing geometrical variations that deteriorates performance and improper geometry of the bearing due to manufacturing inaccuracies. The possible solution strategy to prevent these failures is the use of suitable anti-wear lubricant additives, by providing grooving arrangement etc. Very precise manufacturing of the bearing geometry at the contact zone is required to minimize the bearing wear.

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