Standard Guide for
Monitoring Failure Mode Progression in Plain Bearings[1]

This standard is issued under the fixed designation D7973; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Oil analysis is a part of condition-based maintenance programs. Despite the wide use for several decades, there is no systematic approach to selecting oil tests based on failure mode analysis. Most users select tests primarily based on oil degradation criteria, minimizing the potential for detecting surface damage and limiting the potential benefits of the oil analysis program. This guide provides an example of justification for oil analysis from a failure standpoint to include both component wear and fluid deterioration.

1. Scope

1.1 This guide covers an oil test selection process for plain bearing applications by applying the principles of Failure Mode and Effect Analysis (FMEA) as described in Guide D7874.

1.2 This guide approaches oil analysis from a failure standpoint and includes both the bearing wear and fluid deterioration.

1.3 This guide pertains to improving equipment reliability, reducing maintenance costs, and enhancing the condition-based maintenance program primarily for industrial machinery by applying analytical methodology to an oil analysis program for the purpose of determining the detection capability of specific failure modes.

1.4 This guide reinforces the requirements for appropriate assembly and operation within the original design envelope, as well as the need for condition-based and time-based maintenance.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D130 Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water

D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration

D7685 Practice for In-Line, Full Flow, Inductive Sensor for Ferromagnetic and Non-ferromagnetic Wear Debris Determination and Diagnostics for Aero-Derivative and Aircraft Gas Turbine Engine Bearings

D7690 Practice for Microscopic Characterization of Particles from In-Service Lubricants by Analytical Ferrography

D7874 Guide for Applying Failure Mode and Effect Analysis (FMEA) to In-Service Lubricant Testing

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[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.96.04 on Guidelines for In-Services Lubricants Analysis.

Current edition approved Dec. 1, 2014. Published February 2015. DOI: 10.1520/D7973-14.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 *Other Documents:*[3]

ISO 4407 Hydraulic Fluid Power—Fluid Contamination—Determination of Particulate

ISO 11500 Hydraulic Fluid Power—Determination of the Particulate Contamination Level of a Liquid Sample by Automatic Particle Counting Using the Light-extinction Principle

3. Terminology

3.1 *Definitions:*

3.1.1 *bearing failure, n*—the termination of the bearing's ability to perform its design function.

3.1.2 *bearing failure initiation, n*—the moment a bearing starts to perform outside of its design function measured by performance characteristics.

3.1.3 *cause(s) of failure, n*—underlying source(s) for each potential failure mode that can be identified and described by analytical testing.

3.1.4 *design function, n*—function or task that the system or components should perform.

3.1.5 *detection ability number, D, n*—ranking number that describes the ability of a specific fluid test to successfully detect a failure mode's cause or effects. A scale is used to grade detection ability numbers.

3.1.6 *dynamic viscosity* (η), *n*—the ratio between the applied shear stress and rate of shear of a liquid; commonly known as a fluid resistance to flow.

3.1.7 *effect(s) of failure, n*—potential outcome(s) of each failure mode on the system or components.

3.1.8 *failure-developing period (FDP), n*—period from component's incipient failure to functional failure.

3.1.9 *failure mode, n*—physical description of the manner in which a failure occurs.

3.1.10 *failure mode and effect analysis (FMEA), n*—analytical approach to determine and address methodically all possible system or component failure modes and their associated causes and effects on system performance.

3.1.11 *hydrodynamic lubrication (HD), n*—lubrication regime where the load carrying surfaces are separated by a relatively thick film of lubricant formed by a combination of surface geometry, surface relative motion, and fluid viscosity.

3.1.12 *kinematic viscosity* (ν), *n*—the ratio of the dynamic viscosity (η) to the density (ρ) of a fluid.

3.1.13 *occurrence number, O, n*—ranking number that describes the probability of occurrence of a failure mode's causes and effects over a predetermined period of time based on past operating experience in similar applications.

3.1.14 *P-F interval, n*—period from the point in time in which a change in performance characteristics or condition can first be detected (P) to the point in time in which functional failure (F) will occur.

3.1.15 *risk priority number, RPN, n*—a numeric assessment of risk assigned to FMEA process quantifying failure occurrence, severity of impact, and likelihood detection.

3.1.16 *severity number, S, n*—ranking number that describes the seriousness of the consequences of each failure's modes, causes and effects on potential injury, component or equipment damage, and system availability.

3.1.17 *white metal bearing alloys, n*—Metal alloys typically consisting of lead (Pb), tin (Sn) or zinc (Zn) with antimony (Sb) (some known as Babbitt) that are applied as a relatively thin surface to hydrodynamic bearings. These relatively soft materials are used to ensure embeddability of hard particle contaminants entrained in the lubricant and to ensure journal protection should oil supply be interrupted.

4. Summary of Guide

4.1 This guide assists users in the condition assessment of plain bearing applications by selecting oil tests associated with specific failure modes, causes, or effects for the purpose of detecting the earliest stage of failure development.

4.2 There are a number of different industrial systems with plain bearings. For the purpose of demonstrating the applications of this methodology, a simple horizontal bearing housing utilizing a journal type plain bearing lubricated by an oil ring will be discussed. This example is a typical application for many industrial pumps and motors (**1**).[4]

4.3 The focus of this example is to select oil tests capable of detecting and monitoring the progression of specific plain bearing failure modes, their causes and effects, as well as lubricating oil deterioration.

4.4 The expectation is that similar approaches will be applied to other system components lubricated under hydrodynamic condition to detect their specific failure modes.

5. Significance and Use

5.1 This standard is intended as a guideline for the justification of oil test selection for monitoring plain bearing conditions. One should employ a continuous benchmarking against similar applications to ensure lessons learned are continuously being implemented.

5.2 Selection of oil tests for the purpose of detecting plain bearing failure modes requires good understanding of equipment design, operating requirements, and surrounding conditions. Specifically, detailed knowledge is required of bearing design configuration, dimensional tolerances, load directions, design limitations, lubrication mechanisms, lubricant characteristics, and metallurgy of lubricated surfaces. Equipment criticality and accessibility as well as application of other monitoring techniques (for example, vibration, ultrasound, or thermal images) are also critical information in this analysis process. In addition, detailed knowledge of the lubricating oil is paramount.

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[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

5.3 To properly apply the FMEA methodology, users must understand the changes encountered in the system during all operating modes, their impact on design functions, and available monitoring techniques capable of detecting these changes. To demonstrate this approach, Section 6 will provide extensive descriptions of the plain bearing failure modes, their causes, and effects.

6. Failure Modes and their Effects for Plain Bearing Applications

6.1 During steady state operation, plain bearings operate primarily under the hydrodynamic (HD) lubrication regime.

6.2 The main failure modes of plain bearings include rapid breakdown or slow deterioration of the HD oil film.

6.3 The rapid breakdown of HD oil film can be caused by a sudden loss of lubricating oil, rapid change in bearing operating conditions being outside the original design basis, or accidental bearing material disintegration. Wear sensors and other monitoring techniques (for example, bearing surface temperature or vibration sensors) would provide better monitoring capability for this failure mode.

6.4 The slow deterioration of HD oil film can be monitored by in-line oil sensors or off-line oil sample analysis. Based on operating experience, several causes are linked to this failure mode.

6.5 *Causes of Plain Bearing Failures:*

6.5.1 *Change in Dynamic Viscosity of the Lubricating Oil*—Dynamic viscosity at operating temperature is the only property representing the lubricant in the HD oil film thickness calculation. In general, reduction in dynamic viscosity will reduce the oil film thickness. Under severe transient conditions reduction of the oil film thickness may change the HD lubrication condition to a mixed lubrication regime and increase the risk of bearing surface contact and wear. If not corrected, it will cause bearing failure. In opposite conditions when the dynamic viscosity is too high, an increase in drag and friction will result in local heat generation, which may increase the rate of chemical reaction within the oil film. In condition-based maintenance programs, kinematic viscosity at 40 °C (or occasionally at 100 °C) is used to measure this property. The assumption is that in most industrial applications, lubricant density is not significantly changed in the measured temperature of interest (for example, 40 °C or 100 °C) and trending kinematic viscosity can provide adequate prediction of the lubricant's ability to form a reliable and sustainable HD oil film. Newer methods exist or are being developed that will measure dynamic viscosity directly. These methods may in time become commonly used in this application.

6.5.2 *Deterioration of Lubricating Oil Chemistry*—The HD lubrication will also depend on the complex relationship between properties of oil-to-metal adhesion and oil-to-oil cohesion. Applying a constant shear stress on the lubricating oil film may lead to physical damage to the lubricant molecules. The presence of atmospheric oxygen may initiate chemical reactions such as oxidation. High temperature and pressure will accelerate these reactions and lubricant molecules thermal breakdown. Finally, lubricating oil will also deteriorate by the additive depletion process (for example, due to expected performance). The depletion rate would depend on the additive type, applications, and operating conditions. The consequences of these chemical changes will influence several critical properties such as cohesion, adhesion, surface tension, etc. Some visible changes will include an increase in foaming characteristics, air release, sludge and varnish formation, or reduce oil solubility characteristics.

6.5.3 *Increase in Gaseous, Liquid, and Solid Particle Contamination*—All three contaminants types will affect the HD oil film but in different mechanisms.

6.5.3.1 An excessive amount of undissolved gas bubbles in the oil weakens the load carrying capacity of the lubricating film. If the gas is reactive, it can promote chemical degradation of the lubricant which may change the physical characteristics of the oil.

6.5.3.2 A large amount of liquid contaminants, particularly those having significantly different viscosity or density, may influence the dynamic viscosity. If this liquid has chemical reactivity with the lubricant, it could affect its performance characteristics. An example is free water which may not support the external load acting on the bearing. It could also hydrolyze some of the additives, affecting their performance.

6.5.3.3 The presence of a moderate concentration of small solid particle contamination is of less concern in HD lubrication, assuming the particle sizes are smaller than the oil film thickness. However, the presence of solid particles is more harmful in boundary and mixed lubrication conditions. The presence of solid particles may increase the risk of some particles being imbedded in soft bearing surfaces and generate abrasive wear to the mating hard surfaces. In applications with a hydrostatic lift system, large solid particles may scratch surfaces around oil grooves, reducing bearing capability to generate the required hydrostatic lift during start up or shut down operations.

6.5.4 *Change in Bearing Surface Profile or Material Properties*—Changes in the relative speed of bearing surfaces or to the wedge profile will also influence the HD oil film. During start up or shut down operations, plain bearings most likely will operate for a short period under mixed or even boundary lubrication. At these conditions there is an increased risk of bearing surface contact resulting in surface wear, which may temper the profile of the lubricating oil wedge, thus affecting the oil film formation.

6.6 Typical corrective actions related to oil contamination include a total or partial replacement of the existing lubricating oil.

6.7 *Effects of Plain Bearing Failures* (**2**):

6.7.1 In general, five major types of wear are identified: adhesive, abrasive, fatigue, fretting and erosion. For the purpose of this guide, an extended version of the wear classification is proposed in Table 1.

6.7.2 *Bearing Surface Damage Due to Scoring and Wire Wool*—The term scoring is used to describe parallel or circumferential grooves on the bearing surface caused by dirt or debris presence between the bearing and mating surfaces. These particles can originate from wear of journal, bearing surfaces, system components, or from the surrounding environment.

TABLE 1 Wear Classification of Plain Bearings with Failure Mode Effects for Plain Bearing Application

Wear Classification	Failure Mode Effects
Abrasive and adhesive wear	Scoring Wire wool Wiping
Fatigue	Cracking
Erosion	Groove formation
Fretting	Pivot Damage
Chemical	Corrosion
Electrical	Electrolysis (pitting) Rotating Magnetism
Thermal	Overheating/varnish Anisotropy
Metallurgical	Hydrogen blistering Tin migration Delamination

Small particles may also cause polishing of bearing surface that will have little effect on the bearing performance, providing the roughness and particle size do not exceed the thickness of the HD oil film. Large particles usually generate deep scores on the soft bearing surface or become embedded in the soft material generating scores on hard journal surface. Severe cases of damage to the mating surface can occur when shaft material contains chromium or manganese. Large embedded particles (approximately 1 mm) containing chromium or manganese in excess of 1 % may form a hard deposit of material by reaction with the steel journal. This mechanism is self-propagating when started and is usually referred to as "wire wool" damage. (2)

6.7.3 *Bearing Surface Damage Due to Wiping*—Bearing materials are normally chosen for their ability to conform to the mating surface. Therefore a slight wipe near one edge of the bearing indicates that the bearing surface layers melt and wipe in order to accept a particular configuration. Severe wipes lead to a new film thickness profile. Some associated problems with tighter clearances may occur during rapid start up of a cold machine, where the heat generated within the oil film may cause the shaft temperature to rise more rapidly than the bearing housing. Differential expansion of the shaft can cause a temporary reduction in bearing clearance, which in severe cases may cause metal-to-metal contact in the zone of minimum clearance. (2)

6.7.4 *Bearing Surface Damage Due to Cracking*—Cracking occurs when dynamic loads exceed temperature dependent white metal bearing alloy strength and is generally attributed to fatigue. A characteristic of fatigue damage is that the cracks may reach areas near the bond but they will then propagate through the white metal bearing alloy, leaving a portion of this alloy still adhering to the backing. The remaining white metal bearing alloy is often polished by the loose particles over a period of time. The fatigue strength of white metal bearing alloys decreases with increased temperature. Partial loss of oil supply may result in overheating and produce fatigue damage. Intergranular cracking is another form of fatigue mechanism and may be caused by a short period of overheating. The high temperature zone extends deeper than the surface layer of a single wipe so that more of the white metal bearing alloy is weakened. Frictional forces on the surface from contact with the shaft may cause partial shearing of the white metal bearing alloy opening up the cracks. This type of damage often extends only about half way through the thickness of the lining, presumably because the lower layer has more strength, being cooled from the backing. In general, surface cracking causes high vibration. (2)

6.7.5 *Bearing Surface Damage Due to Erosion*—High velocity regions, particularly at bearing edges or around sudden changes in bearing steps, may cause bearing material removal parallel to lubricating oil flow. This will form "canyons" which may change lubricant flow pattern, reducing the local film thickness and oil load carrying capacity. This wear may be amplified by the presence of solid particles in the oil. Another cause of erosion in journal bearings is cavitation where the fluid pressure increases in the load zone of the bearing. No metal-to-metal contact is needed. In the cavitation process vapor bubbles in the fluid are formed in low-pressure regions and are collapsed (imploded) in the higher-pressure regions of the oil system. The implosion can be powerful enough to create holes or pits, even in hardened metal when the implosion occurs at the metal surface. (2)

6.7.6 *Bearing Surface Damage Due to Pitting*—In most cases, pits have a hemispherical form, uniformly distributed over the zone area and may also be found on the mating surface. One cause of pitting is the discharge of an electric current through the oil film, resulting in spark erosion. In such cases, the pits are clean and shiny. If the pits have a black deposit, the pitting is attributed to a different mechanism.

6.7.7 *Bearing Damage Initiated by Fretting on a Pivot*—The reddish-oxide is formed by fretting around the concentrated contact area at the pivot of pad bearings. It may be caused by pad overload or external vibration from adjacent machinery. Fretting damage may also occur during standby operation. (2, 3)

6.7.8 *Bearing Surface Damage Due to Corrosion*—Corrosive wear is caused by increased oil acidity due to formation of oxidation or hydrolysis products, decomposition of some oil additives or the presence of some contaminants such as water or coolant. This wear mechanism leaches certain elements from the soft bearing materials, leaving the upper bearing surface layer porous and weak. Incompatibility between bearing material and lubricant may also promote the corrosion process. The consequence of this wear is a reduction in the bearing's load carrying capacity. Corrosion can also cause pitting, although this is not common for tin based white metal bearing alloys. Black tin oxide can be produced by excessive water contamination. These pits are characteristically uneven. Usually this type of corrosion is accompanied by rusting of exposed steel surfaces. (2)

6.7.9 *Bearing Surface Damage Due to Electrolysis and Rotating Magnetism*—Electrical discharge through the oil film may occur due to faulty insulation or grounding, build up of static electricity or the presence of an inadvertent rotating magnetic field done during some repair or maintenance activities. The discharge can occur at very low voltage and result in severe pitting on bearing surfaces. Although the lubricant film is acting as an insulator, this may be disrupted by the presence of contaminants (such as water) or cavitations. Electrolysis usually causes pitting while rotating magnetism can also generate "worm" tracks. The consequence of this wear damage is a reduction of the load carrying capacity with the change in the bearing surface profile. (**2**)

6.7.10 *Bearing Surface Damage Due to Overheating and Varnish*—Heat generated from the oil shearing process may cause a local reduction in oil viscosity and film thickness, which can further raise oil temperature. In turn, this may oxidize some oil molecules, forming varnish on the bearing surfaces. Since white metal bearing alloy strength depend on temperature, this can lead to material softening and flowing of the upper layer. Although wiping does not necessarily occur under such conditions, surface deformation, cracking and discoloration are typical effects of overheating. The consequences of overheating are the reduction of load carrying capacity and loss of film thickness due to the presence of the varnish layer. (**2**)

6.7.11 *Bearing Surface Damage Due to Anisotropy*—Due to uneven thermal expansion of the tin white metal bearing alloys, severe thermal cycling may lead to cracking along the grain boundaries. This will result in a polishing pattern of white metal bearing alloy surfaces and in extreme cases can cause surface cracking. (**2**)

6.7.12 *Bearing Surface Damage Due to Hydrogen Blistering*—Diffused hydrogen from the steel backing shell stops at the white metal bearing alloy bond line because it cannot diffuse through this alloy. As a result, the hydrogen atoms will build up, causing local pressure and breaking the metallurgical bond. The consequence of this process is loss of clearance at the blister leading to local overheating and damage. (**2**)

6.7.13 *Bearing Surface Damage Due to Tin Migration*—This damage affects copper, copper alloy pads, or shell material. At environmental temperature above 90 °C, tin continues to diffuse to the bond line, forming a thicker layer of copper-tin alloys, leading to a hard, brittle bond line. Over time, white metal bearing alloy lining can completely separate from its backing under minimal impact load. The separation of white metal bearing alloys during operation could lead to loss of clearance, overheating and in extreme conditions to catastrophic bearing failure. (**2**)

6.7.14 *Bearing Surface Damage Due to Delamination*—The microstructure of tin-based white metal bearing alloy consists of a soft solid solution matrix and intermetallic compounds that are harder than the matrix. One of the degradation mechanisms involves rapid cooling which suppresses formation and growth of the intermetallic compound cuboids and increases hardness.

7. Application of FMEA for Plain Bearings

7.1 *Generic Introduction:*

7.1.1 In accordance with Fig. 1, FMEA Flowchart from Guide D7874, users must first identify all lubricated components in the selected equipment for this analysis. For each component (for example, plain bearing) users must identify all possible failure modes, causes and effects and then apply the appropriate severity and occurrence numbers. The next step is to prioritize the failure modes based on criticality numbers (for example, product of each severity and occurrence numbers).

7.1.2 Table 1 from Guide D7874 standard should be used to determine if oil analysis testing is the preferable approach for detecting early stages of bearing failure or another maintenance strategy should be applied (for example, inspection).

7.1.3 For the selected failure modes, end users should identify all available oil analysis test methods, in-line oil or other sensors and assign appropriate detection ability numbers. This step may also be used to justify purchase of a new instrument having better detection capability than the existing one if it is required to meet the criteria.

7.1.4 In cases where the existing oil test method has inadequate detection capability of identifying the specific failure mode, other condition monitoring techniques should be considered (for example, vibration monitoring, infrared thermography, etc.). If the other monitoring technique is also inadequate in detecting the failure, then users may accept time-based maintenance (for example, periodic inspection) or take the risk to operate the machine with inadequate detection of a particular failure mode, cause or effect.

7.1.5 There are several factors affecting the value of the presented methodology and users must apply their own judgment and experience in selecting appropriate severity, occurrence and detection capability numbers. It is suggested users generate a single table for all failure modes, causes and effects associated with all considered oil tests and sensors so the strength and weakness of the condition monitoring program can be recognized.

7.2 *Example of FMEA Methodology for Plain Bearing Applications:*

7.2.1 The methodology being demonstrated is based on a horizontal, medium size bearing housing with white metal bearing alloys (Fig. 1). The bearing is lubricated by a nonmetallic oil ring with the oil type being a rust and oxidation inhibited turbine oil formulated from API Group I base stock.

7.2.2 Due to scope limitations in this guide there is no intention to present all possible oil sampling port locations, sampling hardware and procedures as well as available oil test methods or sensors for each discussed failure mode, cause or effect. The selected example should act as a model to generate the recommended specification table.

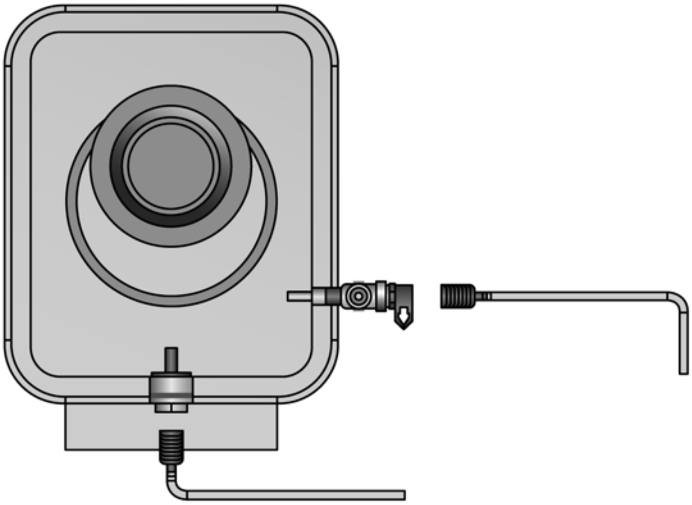

FIG. 1 Schematic Sketch of Typical Horizontal Bearing Housing with Two Sampling Ports

7.2.3 Based on the criticality numbers presented in Table 2, users must apply judgment as to which failure modes, causes and effects are good candidates for the primary condition monitoring program. The chosen limit in Table 2 (for example, the value "SxO" equals 6) is a subjective number, which should take into account the past operating experience, user capability of applying condition-based maintenance program or other inputs. Based on this assumption, only the following failure modes, causes and effects have been selected for the condition monitoring program: change in dynamic viscosity, oil contamination, wiping, scoring, overheating, change in lubricant chemistry, and corrosion.

7.2.4 Users should prioritize the list of the selected failures based on the ranking number from the highest to lowest and select possible oil test methods or sensors capable to detect these failures.

7.2.5 Table 3 provides the final list of failure modes, causes and effects with the associated list of oil tests and sensors having potential for early detection.

TABLE 2 Determination of Criticality Numbers

Failure Modes, Causes and Effects of Plain Bearings		Assigned Value		Ranking
Change in Oil Conditions	Change in Dynamic Viscosity	Severity (S)	4	1
		Occurrence (O)	3	
		SxO	12	
	Change in Lubricant Chemistry	Severity (S)	3	4
		Occurrence (O)	2	
		SxO	6	
	Contamination	Severity (S)	3	1
		Occurrence (O)	4	
		SxO	12	
Adhesive & Abrasive Wear	Scoring	Severity (S)	3	3
		Occurrence (O)	3	
		SxO	9	
	Wire Wool	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
	Wiping	Severity (S)	5	2
		Occurrence (O)	2	
		SxO	10	
Fatigue	Crack	Severity (S)	5	Periodic Inspection
		Occurrence (O)	1	
		SxO	5	
Erosion	Bearing Surface	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
Fretting	Pivot Damage	Not applicable for this bearing design		
Chemical	Corrosion	Severity (S)	3	4
		Occurrence (O)	2	
		SxO	6	
Electrical	Electrolysis	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
	Rotating Magnetism	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
Thermal	Overheating	Severity (S)	3	3
		Occurrence (O)	3	
		SxO	9	
	Anisotropy	Severity (S)	2	Periodic Inspection
		Occurrence (O)	2	
		SxO	4	
Metallurgical	Hydrogen Blistering	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
	Tin Migration	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	
	Delamination	Severity (S)	3	Periodic Inspection
		Occurrence (O)	1	
		SxO	3	

TABLE 3 Example of FMEA for Plain Bearings in Circulating Oil System

Failure Causes and Effects of Plain Bearings		Oil Test	Option One		Option Two		Option Three	
Failure Causes and Effects	Change in Dynamic Viscosity	Test Method	Viscosity Sensor		Kinematic Visc@40C (D445)			
		Sample Location	Drain	Oil Level	Drain	Oil Level Level		
		SxO	12	12	12	12		
		D	5	5	4	4		
		RPN	60	60	48	48		
	Contamination	Test Method	FTIR (D7418)		Karl Fischer (D6304)		Automatic Particle Counter (ISO 11500)	
		Sample Location	Drain	Oil Level	Drain	Oil Level	Drain	Oil Level
		SxO	12	12	12	12	12	12
		D	4	4	4	3	4	3
		RPN	48	48	48	36	48	36
	Wiping	Test Method	Wear Sensor (D7685)		Automatic Particle Counter (ISO 11500)		AES (D5185)	
		Sample Location	Drain	Oil Level	Drain	Oil Level	Drain	Oil Level
		SxO	10	10	10	10	10	10
		D	3	2	3	2	2	2
		RPN	30	20	30	20	20	20
	Overheating	Test Method	Temperature Sensor		FTIR (D7418)		ASTM Color (D1500)	
		Sample Location	Drain	Oil Level	Drain	Oil Level	Drain	Oil Level
		SxO	9		9	9	9	9
		D	5		4	4	3	3
		RPN	45		36	36	27	27
	Scoring	Test Description	Automatic Particle Counter (ISO 11500)		Analytical Ferrography (D7690)		Wear Sensor	
		Sample Location	Drain	Oil Level	Drain	Oil Level	Drain	Oil Level
		SxO	9	9	9	9	9	9
		D	3	2	4	3	2	2
		RPN	27	18	36	27	18	18
	Change in Lubricant Chemistry	Test Description	FTIR (D7418)		Acid Number (D664)			
		Sample Location	Drain	Oil Level	Drain	Oil Level		
		SxO	6	6	6	6		
		D	4	4	3	3		
		RPN	24	24	18	18		
	Corrosion	Test Description	Acid Number (D664)		Copper Corrosion (D130)		Rust Test (D665)	
		Sample Location	Drain	Oil Level	Drain	Oil Level	Drain	Oil Level
		SxO	6	6	6	6	6	6
		D	3	3	2	2	2	2
		RPN	18	18	12	12	12	12

where:
D – Detection ability number
O – Occurrence number
S – Severity number
RPN – Risk priority number

7.2.6 In this example, the remaining failure modes, causes and effects cannot be effectively monitored and another strategy should be used (for example, periodic inspection) to determine their occurrence.

7.2.7 The sampling location identified as "Drain" indicates the oil sample collected from the bearing housing drain valve via an extended vertical tube. The location "Oil Level" indicates an oil sample collected from the side of the bearing housing oil sampling suction hardware. Based on the performed analysis in Table 3, sampling from the "drain" is the preferable location for this application.

7.2.8 In many industrial applications there are a number of different options for collecting oil samples and all of them should be considered in this analysis. For example, a possibility of sampling from an external recirculation filtration unit may also be considered. Contaminants collected from such filters may provide valuable information on bearing condition as well as maintaining a clean environment.

7.2.9 Based on the calculated risk priority numbers, end users can select the best oil test method or sensor to detect and monitor progression (RPN) of each selected failure mode, cause or effect.

7.2.10 It is the judgment of the user, based on the operating experience, to decide if the RPN is adequate to provide early warning of the failure or if another instrument, sensor or different condition monitoring method should be employed.

7.3 *Sampling Frequency:*

7.3.1 Sampling frequency should be determined based on the P-F interval for each monitoring failure mode, cause or effect.

7.3.2 The P-F interval is usually estimated based on input from component manufacturers and operating experience in similar applications. In the presented case of a small bearing housing, a typical sampling interval varies from 8 to 13 weeks. However, the best option is installation of an in-line sensor capable of continuous monitoring of some properties (for example, viscosity, acidity, contamination). When required, an oil sample may be collected for more analysis, especially for critical applications.

7.4 *Overview Comments:*

7.4.1 In the presented example, the values of the FMEA parameters (for example, severity, occurrence and detection ability) for other system components such as pump or motor components will also need similar FMEA templates.

7.4.2 Operating experience may provide new data which can influence the selection of test methods and assigned values for FMEA analysis. Therefore, periodic review of the FMEA templates is recommended to justify the oil test selection process.

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