EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Lube Notes

December 2020

Technical tips on lubricants and lubrication methods for power plant maintenance and engineering personnel

Note Number 1

Expected Operating Temperatures for Babbitted Bearings

Query: What general temperature range should I expect for a babbitted bearing during normal operation? Our utility is trying to establish alert and alarms limits for various components for continuous online monitoring and is looking for guidance.

Response: The short answer is that operational temperatures vary for each component based on bearing design, application requirements, temperature monitoring, and lubricant used. The safe bet is to always consult the equipment original equipment manufacturer (OEM) for guidance. In general, temperature ranges vary from 165°F (74°C) to 225°F (107°C) during normal operation. More details are provided in the Understanding Bearing Composition section of this article.

Analysis: Babbitt bearing metal alloy was invented by Isaac Babbitt in 1839. The alloy described in his patent was 89% tin, 9% antimony, and 2% copper. This is similar to the Alloy #2 babbitt metal that is commonly used today.

Understanding Bearing Composition

To determine the general operating temperature range of a babbitt metal bearing, also called a *white metal bearing*, metal composition must be understood first. Babbitt bearings come in two different bases—tin base and lead base. The chemical composition of the alloy metals is controlled by ASTM B-23, Standard Specification for White Metal Bearing Alloys. Table 1 shows the composition and properties of tin- and lead-based babbitts. These percentages are defined to aid in reviewing oil analysis reports along with the melting point temperatures.

Key elements to look for in an oil analysis report for tin-based babbitt bearing are tin, antimony, and copper. For a lead-based babbitt bearing, lead, antimony, and tin are the key elements. The melting point temperatures range from 358°F (181°C) to 479°F (249°C). Babbitt alloy metals are subject to creep at elevated temperatures within a hydrodynamic film. This occurs at around 375°F (190°C) for bearing loads below 200 psi (13.79 bar) to about 260–270°F (127–132°C) for steady loads of 1000 psi (68.95 bar). As these upper temperatures are reached, the babbitt is subject to surface creep with rippling on the surface and possible wiping. In many cases, the babbitt is smeared rather than melted (see Figure 1). When wiping occurs in power-generating facilities, large particles are generated that will not be evident in oil analysis. Evidence will be seen in strainer baskets as flakes of shiny metal.

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Lube Notes…

EPRI's Nuclear Maintenance Applications Center (NMAC) is pleased to present another in our series of Lube Notes.

If you have questions regarding these notes or lubrication practices in your plant, contact Nick Camilli, EPRI, 1300 West W.T. Harris Blvd., Charlotte, NC 28262, 704.595.2594, ncamilli@epri.com.

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Table 1
Composition and properties of tin- and lead-based babbitts (Source: EPRI 1021780)

Tin-Base Babbitts

Alloy	Specific Gravity	Composition, %				Yield Point*				Ultimate Strength*				Brinell Hardness		Melting Point		Complete Liquefaction	
						psi		MPa		psi		MPa							
		Cu	Sn	Sb	Pb	66°F	212°F	19°C	100°C	66°F	212°F	19°C	100°C	68°F	212°C	°F	°C	°F	°C
1	7.34	4.56	90.9	4.52	None	4400	2680	30.3	18.5	12,850	6050	88.6	41.7	17.0	8.0	433	223	700	371
2**	7.39	3.1	39.2	7.6	0.03	6100	3000	42.1	20.7	14,900	8700	103	60.0	24.5	12.0	466	241	669	354
3**	7.46	8.3	83.4	8.3	0.03	6800	3100	46.9	21.4	17,600	9900	121	68.3	27.0	14.5	464	240	792	423
4	7.52	3	75.0	11.6	10.2	5550	2150	38.3	14.8	18,150	8900	124	31.4	34.5	12.0	363	184	583	306
5	7.75	2	65.5	14.1	18.3	8660	2150	59.7	14.8	18,060	8750	125	60.3	22.5	10.0	358	181	565	296

Lead-Base Babbitts

Alloy	Specific Gravity	Composition, %					Yield Point*				Ultimate Strength*				Brinell Hardness		Melting Point		Complete Liquefaction	
							psi		MPa		psi		MPa							
		Cu	Sn	Sb	Pb	As (max)	66°F	212°F	19°C	100°C	66°F	212°F	19°C	100°C	68°F	212°C	°F	°C	°F	°C
6(e)	9.33	1.5	20	15	63.5	0.15	3800	2050	26.2	14.1	14,550	8060	100	55.6	21.0	10.6	358	181	581	305
7(f)	9.73	0.50	10	15	75	0.60	3550	1600	24.5	11.0	15,650	6150	108	42.4	22.5	10.5	464	240	514	268
8	10.04	0.50	5	15	80	0.20	3400	1760	23.4	12.1	15,600	6150	108	42.4	20.0	9.5	459	237	522	272
10	10.07	0.50	3	15	83	0.20	3350	1850	24.5	12.8	15,450	5750	107	39.6	17.6	9.0	468	242	507	264
11	10.28	0.50	-	15	85	0.25	3050	1400	21.0	9.65	12,800	5100	88.2	35.2	15.0	7.0	471	244	504	262
12	10.67	0.50	-	10	90	0.25	2800	1250	19.3	8.62	12,900	5100	88.9	35.2	14.5	6.5	473	245	498	259
15(g)	10.05	0.50	1	15	82	1.40									21.0	13.0	479	249	538	281
16(f)	9.55	0.50	10	12.5	77	0.20									27.5	13.6	471	242	495	257
19	10.50	0.50	5	9	95	0.20					15,600	6100	108	42.1	17.7	8.0	462	239	495	257

*In compression.
**Babbitts predominantly used by electric utilities (ASTM B23 alloys)

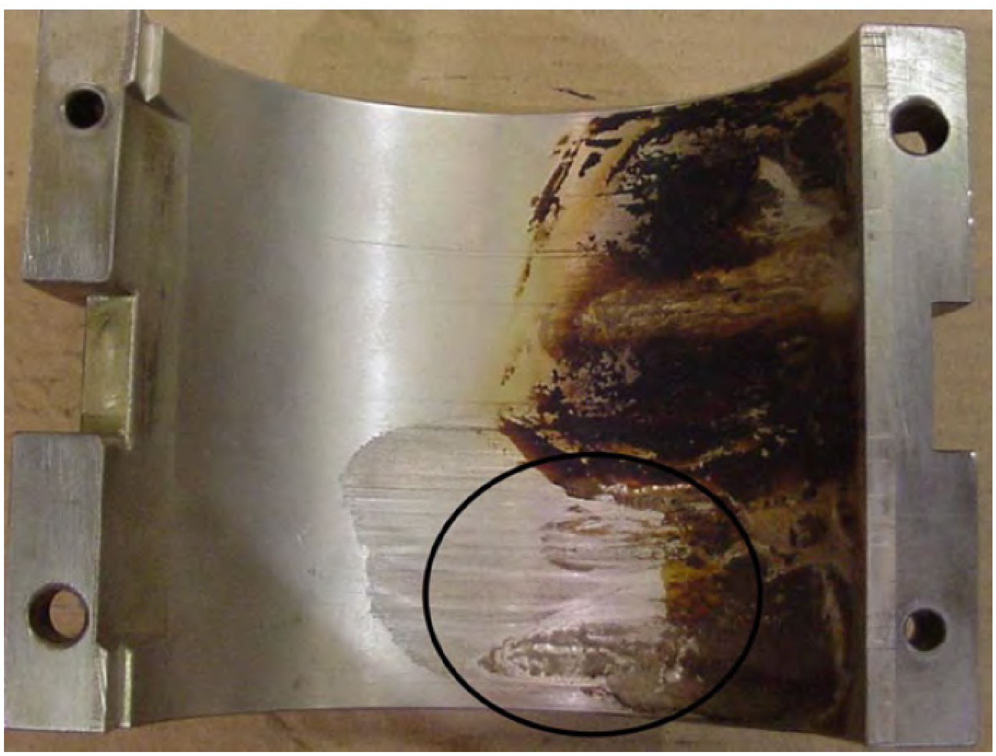

Figure 1
Smearing and evidence of varnish of a journal bearing

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Additionally, vibration and temperature signals can indicate that damage has occurred to the babbitt. Because of the oil film layer present, vibration spikes indicate that the wipe will be short-lived and overall vibration level might not increase dramatically. If displacement probes are installed near the bearing, orbital analysis can show a change in the shaft center line location. Temperature of the bearing can also decrease if additional oil is allowed to flow into the bearing because of the potential increase in the flow area in between the bearing and shaft.

In general, tin-based babbitt has excellent load carrying characteristics where lead-based babbitt has been used for lower loads and moderate temperatures (No longer manufactured because of worker safety and environmental concerns). Babbitt is soft and is used as a sacrificial material and will protect the shaft if a failure or anomaly occurs. Because of the softness of babbitt metal, particles can become embedded from oil that has a high particle count and can cause a bearing to run hotter.

General Temperature Measurement and Probe Placement

In the power generation industry, almost all permanently installed instruments are either thermocouples or resistance temperature detectors (RTDs). On average, about 90% of these are thermocouples, and the other 10% are RTDs. Although not widely used compared to thermocouples and RTDs, fiber-optic temperature sensors and microsensors are also used in the power industry.

Thermocouple placement for sleeve and tilting pad bearings will have a direct effect on the temperature measurement. Equipment OEMs typically define thermocouple placement requirements based on ease of replacement, ease of installation, expected location of the hot spot, and customer experience. Therefore, the location of thermocouple varies vastly across the industry (see Figure 2). American Petroleum Institute Standard 670, Machinery Protection Systems, is a great reference for suggested location of temperature sensors.

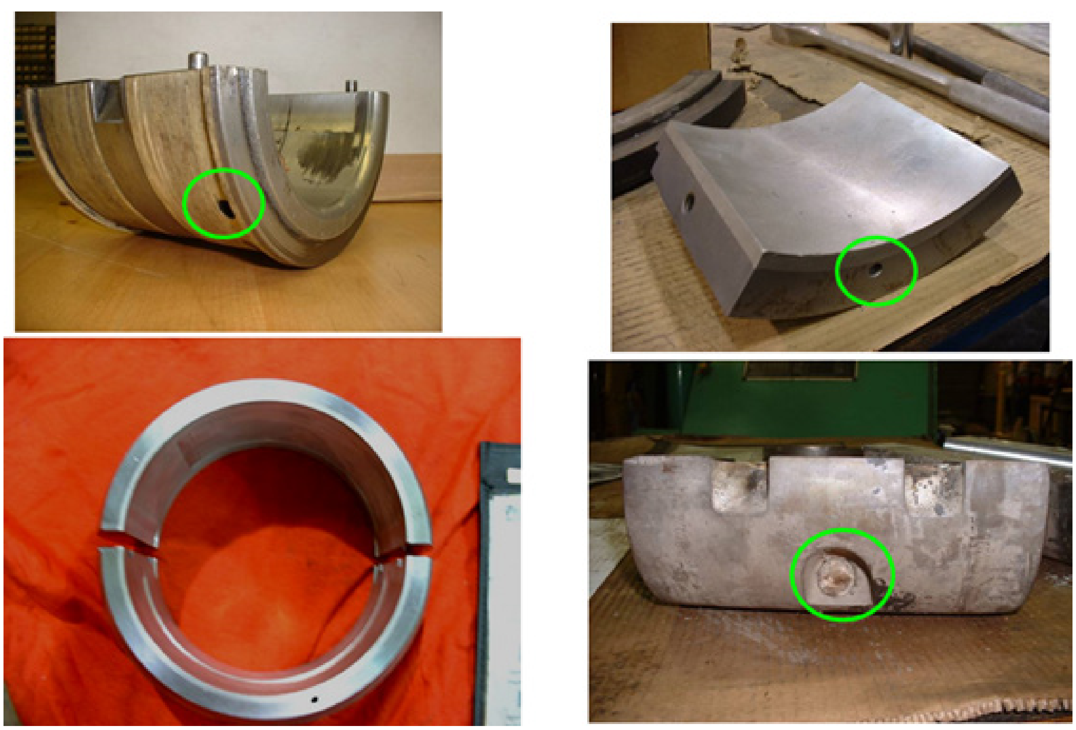

Figure 2
Examples of thermocouple placement on sleeve and tilting pad bearings
Courtesy of Pioneer Motor Bearing

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For each of these bearings, the load point is where the temperature is the highest, although the load point can vary with operational changes, including degradation. With the elevated temperatures, the viscosity of oil drops, allowing the shaft to ride closer to the bearing surface. As the viscosity declines over time, the temperatures in the bearings can elevate. Monitoring viscosity and maintaining it within the OEM specifications will aid in maintaining normal operating temperatures.

The material between the sensor and the bearing surface will affect the accuracy of the reading. If the backing material has a high thermal conductivity like copper, the reading will be more accurate and responsive than a backing material of steel. Nevertheless, there is going to be a temperature drop between the surface of the bearing and the tip of sensor. Different manufacturers build bearings with different distances between the probe tip and bearing surface. This distance for an embedded sensor can vary from 0.030 to 0.060 in. (0.762 to 1.524 mm); larger separation distances are found on bearings for auxiliaries. With this in mind, there should be some conservatism in choosing an alert and alarm temperature setpoint.

Note: Industry operating experience has shown that new bearings will run a little hotter (approximately 15°F [8.3°C]) until the break-in/run-in occurs. Upon initial operation, the shaft and the bearings will conform to each other and create wear. After the break-in is complete, temperatures should return to normal. This will cause a change in the oil analysis trend of wear metals for a short duration.

Various sources indicate the maximum operating temperature for babbitt is 300°F (149°C). For motors, 180–190°F (82–88°C) is considered running hot. For turbine applications, an alarm setpoint at 185°F (85°C) with a trip at 205°F (96°C) is common. Most equipment will operate at less than 180°F (82°C). From a lubricant standpoint, the lubricant life will be cut in half for every 18°F (-8°C) above 150°F (66°C). For equipment operating close to the alert range, the oxidation levels in the oil must be monitored closely prior to varnish occurring.

Conclusion: The general temperature range for a babbitted bearing can vary from machine to machine. The differences are caused by the material (alloy number) that the babbitt is made from, the backing material used in the bearing, load on the bearing, and the distance that the temperature sensor is located from the bearing surface. With design being a major factor, OEM-set limits are the best course to follow for temperature limits. When limits are unavailable, the conservative decision for large steam turbines and generators is to set the alarm temp at 185°F (85°C) with a trip at 205°F (96°C) and adjust/increase limits as more knowledge is gained on the design of the bearing and loading. ***Note***: Operating at the elevated temperatures shortens the life of the oil considerably and must be monitored closely to prevent varnish deposits.

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Note Number 2

Membrane Patch Colorimetry Testing in Electrohydraulic Control Systems

Query: What tests can I perform to determine whether I am susceptible to varnish in my electrohydraulic control (EHC) system?

Response: With steam turbine applications, varnish can be found in tanks, sumps, and bearings. It can be challenging to remove and ultimately cause performance issues. For bearing applications, it can affect the oil film thickness, heat transfer, and/or cause scoring. In EHC systems, varnish on servo valve spools and/or orifices can cause them to stick and/or be erratic. In solenoid valves, it can cause valve sticking and/or burning out of the coils.

In general, utilities rely on a combination of total acid number (TAN) (ASTM D664 and D974), patch (hexane) test, color test (ASTM D1500), and membrane patch colorimetry (MPC) (ASTM D7843) to detect and prevent varnish in EHC systems. The water content by Karl Fisher (ASTM D6304) is also especially important to prevent fluid degradation (hydrolysis) because of excessive water. Frequencies of these tests and the other important ones can be varied based on past history and original equipment manufacturer (OEM) recommendation. The complete suggested routine EHC fluid test program can be found in Table 4-14 of EPRI report 3002003594, *Electrohydraulic Control (EHC) Fluid Maintenance Guide.*

Analysis:

Total Acid Number

As fluid is used, acidic compounds can be formed. The typical maximum limit for the TAN test is 0.2 mg KOH/g. Industry experience has shown that 0.1 mg KOH/g is a better target. The longer that no action is taken and the higher the acid number rises, the more difficult it is to restore the fluid. The reason is that the degradation process is autocatalytic, which means that the rate of degradation increases with time. In addition, if the acid number gets too high, the traditional purification media can result in high metals in the fluid and worse problems, such as gels and valve sticking. A fluid change might be required. A purification media change, such as fuller's earth, is recommended when the TAN shows an increase of 0.05 mg KOH/g in two consecutive samples and/or no decrease. Also, with fresh purification media there should be a decrease; if not, check that it was done, that it was done properly, and that the flow and pressures are correct.

Patch (Hexane) Test

To get a measure of the deposit forming tendency of the fluid, a sample is mixed with hexane solvent, allowed to sit, and then filtered through a 0.45-µm patch. The color is compared against a standard, ASTM D-2276 Appendix A3, B scale. The scale goes from B1 to B10 with B10 being the darkest. New fluid would be a B1 and used fluid a B3 or so. A B6 or higher could be cause for further actions. A dark sample could be an indicator of rapid servo valve and filter plugging, which will lead to increased maintenance and can be particularly frustrating if the traditional fluid maintenance actions are not effective. If the root cause is not corrected, the fluid will degrade faster and additional problems can be expected.

Color Test

Color is normally tested by ASTM D-1500. This is a comparative method with a range of 0–8 going from clear though amber to red and eventually to almost black. Note that the test was developed for mineral oils; therefore, the actual colors are not exactly the same because phosphate esters typically do not go through a red phase. If they

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do not contain dyes, they go from clear or light amber, to darker amber, and then to dark brown to black in color. Darkening usually arises from thermal overstressing and can lead to varnish formation and deposits in the system. If caught early, it might also be possible to save the fluid charge so that a change is not necessary.

Membrane Patch Colorimetry

The MPC test is the newest of the battery of tests to detect potential varnish issues. Originally developed for detecting varnish potential in mineral oils, the test can be and has been modified for EHC fluids. There are only a few commercial labs that have this expertise. The challenge is the ability for the test to determine the difference between carbon/coke and varnish. Fluid that has dieseling (excessive air) problems is frequently and erroneously flagged as having high varnish potentials because of the carbon/coke that is produced. With the complexity of this test, it is recommended to trend results from one lab.

MPC is given as ASTM D7843, Standard Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils Using Membrane Patch Colorimetry. To quote from the standard, this test method extracts insoluble contaminants from a sample of in-service turbine oil onto a patch and the color of the membrane patch is analyzed by a spectrophotometer. The results are reported as a ΔE value, within the CIE LAB scale. This is made of three parameters where a* is positive in the red direction and negative in the green direction, b* is positive in the yellow direction and negative in the blue direction, and L* is positive in the lightness direction and negative in the darkness direction.

Phosphate ester MPC measurements can produce the following three possible outcomes:

- When ΔL and $\Delta(a + b)$ are both low, there is little amber-brown or black contribution to patch color. These patches are light because there are few or no fine insoluble contaminants and the EHC fluid is in good condition.
- When ΔL is high but $\Delta(a + b)$ is low (black quadrant), the patch is dark with little or no amber-brown contribution. The EHC fluid is in poor condition owing to the presence of black carbonaceous insolubles; it is less likely to produce varnish.
- When ΔL and $\Delta(a + b)$ are high (red quadrant), the patch is dark because of intense amber-brown deposits. The EHC fluid in this scenario is in poor condition, featuring a high level of phosphate ester precursors to varnish.

The value can be reported as dE or as the ΔE where this is representative of the differences (delta) between the three values. It is calculated as the square root of the sum of the squares of the differences for the three parameters.

This can directly correlate the insoluble level with the varnish potential of the fluid. Limited test data were available during EPRI's study, but current suggested limits might be 30 dE and achievable 15 dE.

Points to note include the following:

- The ASTM test uses a membrane filter, 47-mm nitro-cellulose, 0.45 µm.
- The ASTM test involves aging the fluid, but this is not always necessary with phosphate ester fluids. For mineral oils, the sample preparation includes heating to 60–65°C for 23–25 hours and then stored between 15°C and 25°C, away from ultraviolet light for an incubation period of 68–76 hours.
- A high value is not always indicative of varnish. This is because a dark fluid that contains soot or color bodies because of the compression of air bubbles might have an extremely high L* value and be black. Although it is not good, it does not necessarily mean varnish.

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- The ASTM procedure does not include weighing the patch, but this can especially useful.
- Some labs do not report the dE but rather the d (a+b) and dL.
- After you have the patch, different solvents can be used to try to determine the composition and, therefore, the cause of the deposits.
- Photos of the patches can be helpful to highlight changes.

Targets: for light to amber-colored fluid, the following have been suggested:

	Achievable	Warning	High
dE	≤15	30	>30
dL	≤20	>20	>30
d (a+b)	≤10	>20	>30
Patch weigh (mg)	≤4	>4	

The photos in Figure 3 are for ΔL and Δ(a+b), which are not reported by all labs. However, the ΔL is reported to show very good correlation with ΔE values, especially at low values.

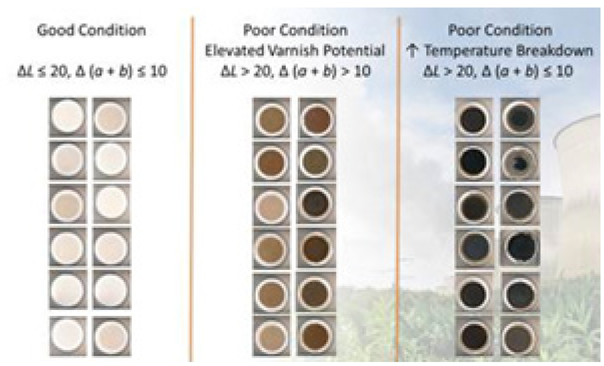

Figure 3
Typical MPC limits to evaluate fluid condition and varnish potential

Another useful document that gives guidance on varnish issues in gas turbines is General Electric Technical Information Letter 1528-3. This covers varnish issues for Group I and II mineral oil-based lubricants. It refers to MPC dE valves associated with different risk levels.

Conclusion: The MPC test should be part of the routine condition monitoring of phosphate ester stream turbine control fluids. If the fluid is known to be in good condition and the servo valve known to be clean, the MPC test should be run at least every two years—possibly scheduled far enough in advance of scheduled outage to be able to include any required corrective actions. At the very least, run it to determine what is normal for that unit. If there is varnish or known fluid problems, the test can be run monthly or even weekly if needed to determine whether the remediation efforts are being successful. Phosphate ester EHC fluids are capable of trouble-free operation lasting for decades if all of the right fluid tests are performed at the right intervals and the fluid maintenance is done correctly.

Note also that this test indicates only whether the current fluid is likely to form varnish deposits. It cannot determine whether there is varnish in the system.

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EPRI, "Electrohydraulic Control Fluid Is Out of Specification," Lube Note #3, December 2017. Covers some of the causes and actions when the acid number is too high and/or not responding.

EPRI, "Electrohydraulic Control Fluid Testing and Interpretation," Lube Note #4, December 2016. Covers the different tests, what they mean, and some actions.

EPRI, "Electrohydraulic Control Servo Valve Maintenance," Lube Note #5, December 2016. Covers new versus rebuilt and the importance of getting feedback in any case about the condition of the screen and of the internals.

EPRI, "High Particle Counts in EHC Fluid," Lube Note #4, December 2014. Covers actions to take when you get a high particle count. Retest, test for source and check pumps, pressure gauges and filters.

EPRI, "New GE Specification for EHC Fluid," Lube Note #2, December 2014. This lists the changes in the specification for new and in-service fluid and the changes to recommended condition monitoring. There are many more tests.

EPRI, "Reducing Water Content with Dry Air Purge Systems," Lube Note #2, December 2016. Shows some of the benefits of lower water contents and the ability to get down to a few hundred ppm easily.

General Electric Technical Information Letter 1528-1, Lube Oil Varnishing, November 2005.

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Note Number 3

EPRI Acoustic Auto Lubricator Concept Now Commercialized

Query: At the 2019 Condition-Based Maintenance (CBM) Users Group conference, EPRI presented on a prototype wireless acoustic auto lubricator. There was a significant amount of interest in the product from utilities and select vendors in the room. What became of that device?

Response: We are happy to announce that, as of October 2020, the device has been commercialized and is available for purchase from UE Systems. UE Systems is active in the power generation CBM community and known globally for its acoustic knowledge and devices. It took the concepts developed in EPRI report 3002015243, *Feasibility and Design of a Prototype Wireless Acoustic Auto Lubricator*, and developed its own device, which is called *OnTrack SmartLube System*.

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Analysis: There are hundreds of grease-related preventive maintenance tasks for motors, fans, and other rotating equipment in power plants. Some of these locations are inaccessible and present additional environmental challenges because of heat and radiation. Operating experience has shown that manual grease addition often lead to overgreasing, mixing of grease products, and/or contamination, all of which have a negative effect on bearing life.

Building on the principles presented in the EPRI report, UE Systems' OnTrak SmartLube System eliminates manual lubrication tasks while allowing for more precise lubrication events. Bearing friction is monitored remotely, using acoustic technology, and, when a change in friction is detected, an alert is sent to the user (see Figure 4). Using real-time bearing friction as the guide, the user can accurately determine how much grease to apply while watching the friction drop to normal values. When the friction level drops to the normal value, the bearing is sufficiently lubricated. This prevents inadequate lubrication or excessive lubrication.

Figure 4
OnTrak SmartLube System and real-time monitoring

After the user is comfortable with the OnTrak SmartLube System, it can be placed in automatic mode, where it will automatically lubricate the bearing based on a set change in friction. In this mode, a designed-for-purpose algorithm is used to ensure the correct greasing process while safeguards are in place to ensure that there is no possibility of overgreasing the bearing.

All activity during and after the lubrication process is recorded for analysis: the time accumulated between lubrication cycles, the amount of grease used during each cycle, and the remaining grease in the lubrication device to ensure that it does not run out.

The UE Systems OnTrak SmartLube System also allows data to be continuously exported to your preferred monitoring software platform so that bearing acoustic levels can be monitored in the same model as revolutions per minute, vibration, and temperature. The SmartLube dashboard will need to be accessed only when changes are needed to be made to the lubrication settings or when connecting new devices.

Conclusion: One of key roles of EPRI as a global research collaborative hub is to be a technology accelerator for the utility industry. Although EPRI does not promote or endorse vendors, it is encouraging to see companies such as UE Systems closely follow EPRI research to develop and commercialize products such as the OnTrak SmartLube System. Contact UE Systems at 800.223.1325 or visit https://www.uesystems.com/smartlube to learn more.

Note Number 4

New High-Performance Multiuse Grease Specification

Query: I am hearing rumblings of a new grease specification on the horizon by the National Lubrication Grease Institute (NLGI). Do you have any details that can be shared at this time, including how it could impact me at my station?

Response: We are following the development of a new high-performance multiuse (HPM) grease specification by the NLGI. This new specification appears to be prompted by efforts to consolidate specifications but primarily in response to addressing sealed-for-life components and advancements in materials, bearings, and machine technology. The new program will focus on certifying HPM greases for industrial applications.

Analysis: The most common grease used in the utility industry is a multipurpose NLGI-2 grease. Add an extreme-pressure additive to the grease, and it even becomes versatile. Fan bearings, pump bearings, gears, motors, chains, and wire rope are all examples of where this grease can be found.

The new HPM grease coming to the market in January 2021 is being driven mostly by the automotive industry. Recall that the difference between industrial and automotive greases is basically neglectable. The choice of grease is primarily based upon the application. The main difference between industrial and automotive greases is that a two-letter designation is often used in the automotive industry to specify the type of grease. For example, greases may be rated as GC or LB. GC is recommended for axle and wheel bearing grease, whereas LB is the industry standard for chassis grease used on tie-rod ends, ball joints, U-joints, and control-arm shafts.

The new HPM grease is not going to replace the automotive grease GC-LB; however, it will open the door to another choice of grease to use. The new HPM will be defined for high load, water resistance, corrosion resistance, low temperature, and long-life applications. Another interesting factor for this grease is that it will enter the marketplace with provisional licensing for ASTM D4170, Fretting Wear Test.

Being an industry grease user, you might ask, “How does this affect me?” The answer is this: the new grease specification will give another choice in choosing a grease to lubricate equipment. According to the new specification, this grease can be used in a wide variety of applications. For example, the NLGI website suggested that it could be used in gearboxes, electric motors, and other applications. This could allow more consolidation of lubricants and reduce the number of lubricants needed for lubrication needs. The lubricant will be classified as long-life and has the potential to reduce the frequency of relubrication. The lubricant is expected to be able to handle high loads, have excellent water resistance capabilities, aid in corrosion resistance, and perform well at low temperatures. The last big advantage will be a reduction in fretting in bearings. To accomplish this goal, the phosphorus chemistry will have to be adjusted without affecting the performance of the other additives. Fretting occurs ever so subtly in bearings of equipment sitting idle next to a running piece of equipment. With this new grease, bearing life will be extended. In other words, this grease will also meet industry needs as well as the automotive industry. New equipment purchased in the future may come lubricated with this new grease. The question of compatibility will have to be addressed. More information will be shared as it is made available.

Conclusion: In summary, industrial and automotive greases may be quite similar and should be treated as such. The new HPM grease has some favorable attributes such as meeting ASTM D4170, Fretting Wear Test, along with high load, water resistance, corrosion resistance, low temperature, and long-life applications. The grease should be looked at favorably with possible advantages of improving machine life. But the questions must be asked and answered before using.

As of September 2020, the NLGI was currently working with the Center for Quality Assurance on next steps of the HPM specification, including pricing and the application and certification process. The NLGI website will provide additional details in the coming weeks. HPM grease will be available in early 2021 for a broad range of markets. NMAC will continue to monitor the release of the specification and any impact it may have on power-generating stations.

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Note Number 5

Air Release Problems Observed in Turbine Fluids

Query: We recently changed out our main turbine oil and observed air bubbles in the sampled fluid. After six months of in-service activity, it appears that the air entrainment has increased and we have started seeing bubbles in the site glass (see Figures 5 and 6).

Figure 5
Sample bottle

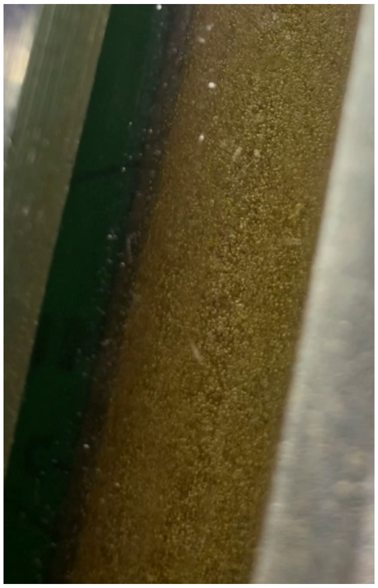

Figure 6
Site glass

Response: It appears that the fluid is experiencing issues with failing air release properties. Agitation of lubricating oil with air in-service can produce a dispersion of finely divided air bubbles in the oil. The volume of the liquid will increase from these entrained air bubbles. As a result, the density of the fluid will also increase. If the residence time in the reservoir is too short to allow the air bubbles to rise to the oil surface, a mixture of air and oil will circulate through the lubricating oil system, as shown in Figure 6. The results of poor air release properties can contribute to inability to maintain oil pressure, incomplete oil films in bearings, and poor hydraulic system performance.

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Analysis: The first question that needs to be understood is the cause of the bubbles in the fluid. Bubbles in a fluid can be caused by two incompatible liquids or fluid with air present. Water is the most common incompatible liquid seen in a turbine fluid. Determining whether the water level is below ~200 ppm (the nominal saturation point) can answer this question quickly.

Air in a fluid can come from poor foam control or air release issues. Testing the fluid for foam properties (ASTM Standard D892) or air release properties (ASTM Standard D3427) can help in answering this question. Additionally, an experienced individual will often be able to tell by looking at the sample. Foam is seen throughout the sample but primarily resides on the surface. The foam bubbles typically rise toward the surface and collide with other bubbles to form larger bubbles that eventually break at the surface level. Bubbles from air release problems tend to reside in the fluid, maintaining near the same size, which is typically small. These are often rising to the surface very slowly with minimum surface foam retention. The fluid total volume will increase for the air being retained.

Many lubricant specifications recommend condemnation levels for both foam and air release. These include ASTM D4378, GEK32568 rev H, Alstom HTGD 90117 V0001U, VGB Guideline VGB-M 416 M, and Siemens Work Standard 800 037 98.

Problem: Foam and air release properties are interfacial properties. They are typically caused by failing fluid compatibility (ASTM Standard D7155); however, base stock chemistry and fluid formulation can also have some effects.

This question was originally approached in a 2005 Lube Note where the original thought suggested a correlation with the choice of antifoam additive used in the turbine oil. Foam control can be handled by the use of acrylate or silicone antifoam additives. Acrylate antifoam additives are not used in formulation packages containing dispersants and detergents additives because the acrylate interacts with the additive's micelles and lose their effectiveness (that combustion engine oil). Acrylate lowers the fluid/air interface in the base stock to allow the bubbles to combine within the fluid and break as they hit the surface. There have been some reports that there are differences between Group I and Group II base stocks. Although this is true, Group II oils are a purer base stock because of the leveling effects of the hydrotreating, which make them more compatible with Group II oils. Therefore, it is easier to treat Group II fluids with the acrylate additive. Group II, being a purer base stock, is also more sensitive to contamination. Therefore, it is easier to fail from less contamination.

Silicone antifoams are used with formulation packages containing dispersants and detergent additives because they are not soluble in the base stock itself and do not interact with the micelles. Silicone forms surface layer on the fluid that will interact with the bubbles being formed, lowering their surface tension and causing them to break. Silicone antifoam should never be used with turbine oil because the silicone additives are easily filtered out by the filter media being used in these systems. It takes little time for the high filtration of a turbine fluid to lose all of the silicone antifoam protection to the filters.

Air release is a base stock attribute. It is a direct effect of the base stock chemistry itself. There are no real effective additives successful in its control. Typically, air release relies on the base purity, surface tension, and air retention. The purer the base stock, the better its release properties. Therefore, the general trend for air release is that the more synthetic or more highly hydrotreated the base stock, the better its air release property—Group II+ is going to be better than Group II, which is better than Group I. This continued line of thinking indicates why the air release values deteriorate with fluid age. With fluid age, there are oxidation and wear products ingression into the fluid to assist in its contamination loss of pure capability.

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The problems that have been observed for air release properties being lost can be most often be related to a fluid contamination issue. New fluid has good air release properties; then, it is put into a sump that was improperly cleaned and we now have contamination—therefore, compatibility issues and loss of the interfacial properties. As the fluid ages, we have all kinds of ingress to deal with, from particle and water contamination to oxidation and additive decomposition.

When we look at a fluid that has been agitated with air, we have a choice of two physical events:

1. The air droplets can be homogenized into small droplets and suspended in the fluid.

2. The air is dissolved or incorporated into the fluid.

When the agitation stops, in Case 1 the bubbles agglomerate and head for the surface based on their size, the fluid surface tension, fluid temperature, and fluid viscosity (following Stokes law). This typically is a foam event. Our concern on reliability relates to the foam being sucked into the intake pump.

For Case 2, when agitation stops, the bubbles disappear or just hang within the fluid. The fluid actually appears to increase in volume. Then, as the fluid sets, the bubbles form and float to the surface. The bubbles also form as the fluid is worked in its hydraulic systems. This means that there is an easier means of getting air into operating regimes.

Conclusion: When bubbles are present in a system, first determine the cause. Test for water content to rule out incompatible fluids. Also, incompatible fluids can come from bearing lubrication used during a main turbine rebuild/assembly (that is, STP oil treatment). Next, determine whether the bubbles stem from poor foam control or air release issues. Recall that foam typically resides at the surface with varying bubble size, whereas air resides within the fluid with a more consistent bubble size. Most often, air release properties are related to a fluid contamination issue. With the oil being only six months old, the lubrication manufacturer should be contacted and requested for assistance on this problem. Some questions to asked are: what the tanker trucks were hauling prior to filling with your turbine oil and is anyone else who received oil from oil refinery having the same problem. The only way to correct this issue is to drain the fluid, thoroughly clean the reservoir/flush, and refill.

Note Number 6

Tips for Successful Inline Oil Analysis Sensor Installation

Query: My site is considering installing some inline oil sensors for online monitoring. What are some of your learnings based on the pilot installations at power generation stations?

Response: Introduction of new technologies to power-generating facilities is often challenging and after the installation of six units across the United States, we have certainly had our share of challenges. Recall that three units are installed on a main turbine lube oil reservoir, two units are on an electrohydraulic control (EHC) system, and one unit is on a boiler feed pump turbine. All FluidMD[1] units were designed and built by IoT Diagnostics in collaboration with EPRI.

Analysis: There are five key learnings that we believe are worthy of sharing related to oil analysis sensor installation and data collection for the EPRI pilots.

[1] *FluidMD* is a registered trademark of IoT Diagnostics.

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Dedicated Oil Supply

Sharing a supply can cause a vacuum or head pressure issues. Using a dedicated oil supply proved to be the best practice. Particle count sensors need a specific undisrupted flow to not only provide a good sample but also to conform to International Organization for Standardization (ISO) 4406, Society of Automotive Engineers classes, and National Aerospace Standard 1638. Pulling from the tank directly would be an ideal oil supply. An example of a nondedicated oil supply would be sharing the oil supply with a coalescing cart. With this configuration, it is hard to determine what the cause of any erroneous sensor data may be. Is the bad data coming within the FluidMD cabinet or from an outside element? If, from an outside element, are they from what it shares the oil supply with or from the oil supply location itself? Having a dedicated oil supply provides a level of control that will only solidify the credibility of the sensor data.

Proper Flow Control

There are two parts to this issue. First, the pump that is used to provide the needed flow across that sensors will need to be sized accordingly. If the size of the pump still cannot provide the adequate flow by itself, flow controls will need to be used. A specific backpressure is required to facilitate not only the flow controls but also the sensors themselves. All of these variables are key to a constant useful data point. If flow control is not appropriate, the sensors can provide a false reading.

Fluid Compatibility

Ensure that sensors are available to provide the level of data pertaining to the oil that is being studied. The system fluid must be compatible with all of the wetted material of the selected sensors. Outside of the sensors, are the internal hydraulics (of the fluid analysis device) compatible with the fluid being tested? All this needs to be ensured before placing a fluid analysis device into the field.

Legacy System/Oil Characteristic Issues

If the system has had legacy issues such as air entrainment or contamination, this can cause sensor faults or damage to the internal components of the FluidMD unit. This was an issue that was experienced with the Parker iCountPD particle counter when it was giving a bubble fault. Initially, the thought was that the pump could have been ingesting air through a failing shaft seal and causing the bubble fault. The pump was replaced, all systems came back online with no problems, but the bubble fault was still present. When looking around to determine a better installation location with a dedicated oil supply line to the FluidMD unit, the site glass caught our attention. The entire tank was full of air entrainment. Issues such as entrained air will never allow for a true ISO count with an inline optical particle counter.

Connectivity

If you plan to send data to a third-party site, make sure that you get information technology and cyber security personnel to buy in before the unit is built. Most sites do not like the idea of data leaving their networks—too much red tape when trying to connect these devices to outside networks. Sometimes the physical connection can be an issue. Even if approval is obtained to pass oil data to outside networks, are there WiFi access points close to where the FluidMD unit will be installed? An alternative may be to have an Ethernet drop near the FluidMD installation site. We have lost a substantial amount of time with some of our pilots as a result of obtaining data sharing agreements.

Conclusion: Proper installation, hydraulic material selection, and the resolution of legacy system/oil issues are vital to sensor operation and accuracy. Having the ability to evaluate the accurate sensor data completes the project. The items noted previously have caused downtime and missed opportunities. It is recommended that anyone who is installing or considering installing inline oil analysis sensors evaluate these key learnings.

Note Number 7

2020 Review of ASTM International Update on D02 Petroleum Products, Liquid Fuels, and Lubricants

Background: EPRI/NMAC is committed to keeping end users informed of current and future ASTM activities that are related to power plant lubrication programs. This helps to keep lubrication engineers up to date with new standards that could impact their program.

The following information is a summary of new ASTM standards from the ASTM website that are either in progress or have been recently released. For this Lube Note, NMAC is specifically interested in activities within the ASTM Committee D02 on Petroleum Products and Lubricants, D02.96 In-Service Lubricant Testing and Condition Monitoring, and D02.CO on Turbine Oils. Details on each of the work items can be viewed by visiting the ASTM website at www.astm.org.

New Standard and Reinstatement Work Items

WK73062 – **New Test Method for Condition Monitoring of Phenol Antioxidant Additives in In-Service Petroleum and Hydrocarbon-Based Lubricants by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometry**. This new standard provides a fast but reliable spectroscopic method for the determination of phenolic compounds in lubricating oils. Phenolic compounds are widely used in engine, hydraulic, and many other oils to protect against oxidation. Knowledge of the remaining antioxidant can help machinery operators recognize severe operating conditions before base oil degradation and machinery failure.

This work Item has passed the subcommittee ballot and has entered the round robin stage to determine a precision statement.

WK70777 – **New Specification for Standard Specification for Polyalkylene Glycol (PAG) Lubricants for Use in Steam and Gas Turbines**. PAG turbine lubricants are currently being used in gas and steam turbine lubricating systems. PAG base stocks are different from mineral oil base stocks in chemical composition because they contain the element oxygen, which mineral oils do not. The properties of the fluids then are not identical and can differ slightly or more significantly. Those differences can dictate different specification test limit parameters and/or different tests from those stated currently in ASTM D4304. End users responsible for the selection of a turbine oil for a steam or gas turbine lubricating system need to have a standard specification for PAG turbine lubricants providing property and performance requirements for reference as they currently do for mineral and other synthetic turbine oils.

This work item is currently in the writing stage. The potential standard is expected to undergo its first ballot review early in 2021.

New or Revised Approved Standards

D7844-20 – **Standard Test Method for Condition Monitoring of Soot in In-Service Lubricants by Trend Analysis using Fourier Transform Infrared (FT-IR) Spectrometry**. This test method pertains to field-based monitoring soot in diesel crankcase engine oils, as well as in other types of engine oils where soot can contaminate the lubricant as a result of a blowby due to incomplete combustion of in-service fuels. The test method uses FT-IR for monitoring of soot buildup in in-service lubricants as a result of normal machinery operation. Soot levels in engine oils rise as soot particles contaminate the oil because of exhaust gas recirculation or a blowby. This test method is designed as a fast, simple spectroscopic check for monitoring of soot in in-service lubricants with the objective of helping diagnose the operational condition of the machine based on measuring the level of soot in the oil. The current passing standard modification adds a calibration curve between the absorbance and percent soot, allowing the reporting of percent soot as well as the standard absorbance value.

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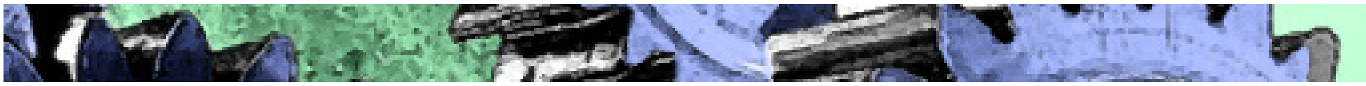

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D7669-20 – **Standard Guide for Practical Lubricant Condition Data Trend Analysis**. This guide is intended to provide machinery maintenance and monitoring personnel with a guideline for performing trend analysis to aid in the interpretation of machinery condition data. The trending techniques taught in this standard can be used for all instrumentation that provides numerical test results. This guide is written specifically for data obtained from lubricant samples. Other data obtained and associated with the machine can also be used in determining the machine condition. This guide provides a trending methodology for assessing changes in lubricant during service. For limits on a specific lubricant parameter used in different system types, users should refer to Practice D4378, Practice D6224, or other established industry criteria, such as from the original equipment manufacturer (OEM). Guide D7720 can be used to determine limits if unavailable through the other references given or to determine actual values for your system. The current modifications of this valuable standard were to refresh the document with updated methodology and improved explanation.

D7416 -09(2020) – **Standard Practice for Analysis of In-Service Lubricants Using a Particular Five-Part (Dielectric Permittivity, Time-Resolved Dielectric Permittivity with Switching Magnetic Fields, Laser Particle Counter, Microscopic Debris Analysis, and Orbital Viscometer) Integrated Tester**. This practice covers procedures for analysis of in-service lubricant samples using a particular five-part (dielectric permittivity, time-resolved dielectric permittivity with switching magnetic fields, laser particle counter, microscopic debris analysis, and orbital viscometer) integrated tester to assess machine wear, lubrication system contamination, and lubricant dielectric permittivity and viscosity. Analyzed results trigger recommended follow-on actions that might include conducting more precise standard measurements at a laboratory. Wear status, contamination status, and lubricant dielectric permittivity and viscosity status are derived quantitatively from multiple parameters measured. This practice is suitable for testing incoming and in-service lubricating oils in viscosity grades 32 mm^2/s at 40°C to 680 mm^2/s at 40°C having petroleum or synthetic base stock. This practice is intended to be used for testing in-service lubricant samples collected from pumps, electric motors, compressors, turbines, engines, transmissions, gearboxes, crushers, pulverizers, presses, hydraulics, and similar machinery applications. The modification of this standard was to add additional precision information.

D4378-20 – **Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines**. This practice is intended to assist the user, in particular the power plant operator, to maintain effective lubrication of all parts of the turbine and guard against the onset of problems associated with oil degradation and contamination. The values of the various test parameters mentioned in this practice are purely indicative. In fact, for proper interpretation of the results, many factors, such as type of equipment, operation workload, design of the lubricating oil circuit, and top-up level, should be taken into account. This practice has been in existence for many years and has gained in popularity to where it is referenced by many OEMs. The current modification was directed toward keeping the information current and relevant to today's operations. As with D6224, Microbiological Contamination, information and recommendations have been added to this practice.

D7155-20 – **Standard Practice for Evaluating Compatibility of Mixtures of Turbine Lubricating Oils**. This practice covers the compatibility of mixtures of turbine lubricating oils as defined by Specification D4304. The methods compare properties of specific mixtures with those of the neat oils after storage at specified conditions. The methods are grouped into the following four tiers of testing types:

- Tier 1—visual appearance
- Tier 2—interfacial properties
- Tier 3—physical and chemical properties
- Tier 4—specific performance properties

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The methods can be used to evaluate new (unused) lubricant compatibility or the effects of adding new (unused) lubricant to in-service lubricant in the system. In the appendix of this practice is a table defining visual ratings of the fluids' compatibility. An addition of an alternative spectroscopic tool for this measurement has been included.

D8323-20 – **Standard Guide for Management of In-Service Phosphate Ester-Based Fluids for Steam Turbine Electrohydraulic Control (EHC) Systems**. This new guide provides recommendations to achieve safe and reliable operation of EHC systems, recommended levels for required corrective action, and suggested management practices. The recommended set of physical and chemical properties of triaryl phosphate esters and their limits have been selected based on past operating experience with various fluids (primarily xylylated and butylated triaryl phosphate esters) used in different EHC system designs under different operating and environmental conditions. This guide is not intended to replace OEM specifications but rather to support users experiencing operating problems by recommending limits based on existing knowledge of triaryl phosphate ester degradation mechanisms. This guide should be used outside the warranty period or in cases where no OEM standard exists or is available.

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