New Techniques in Grease Sampling and Analysis to Complement Condition Based Maintenance Programs

Richard N. Wurzbach
MRG Labs, York, Pennsylvania, USA
rwurzbach@mrgcorp.com

September 20, 2012

Lisa Williams
MRG Labs, York, Pennsylvania, USA

Evan Bupp
MRG Labs, York, Pennsylvania, USA

Summary

Oil analysis is well established as a routine tool to optimize maintenance activities, improve reliability and equipment life and prevent component failures. As part of a comprehensive Condition Based Maintenance program, lubricant analysis is an effective complement to other diagnostic technologies such as vibration analysis, infrared thermography, ultrasonic detection and motor circuit evaluation. However, when the equipment is grease lubricated rather than oil lubricated, the important lubricant analysis piece is often left out of the mix. The reasons for this include challenges in obtaining samples that can be trended, as well as the large sample volumes required for most current standardized tests for greases. Unlike oil, grease does not typically flow uniformly or circulate in the machine, so particulate and contaminants are present in varying concentrations in the grease. When a grease sample is obtained, it cannot be simply agitated to suspend and distribute particulate, as is the case with oil. These fundamental differences present barriers to acceptance of grease analysis as a routine aspect of diagnostic monitoring programs.

New tools have been developed for improved sampling techniques and grease analysis tests have been added to address concerns of sample trending as well as accommodating small sample sizes. These include rheometry, or the flow characteristics of greases. Other new tests are emerging, including die extrusion, to efficiently prepare samples for analysis. Novel sampling aids have been introduced to permit consistent extraction of samples from locations that improve the representative nature of the sample, some of which have been incorporated into ASTM standards. Infrared thermographic monitoring of the flows of greases has provided insight into in-situ grease flow behavior, and has validated these sampling methods and improved understanding of good practices to obtain representative samples.

This paper details infrared studies of grease flow and the use of this information to ensure good sampling practice. Application of this understanding illustrates how new sampling and analysis technologies can produce improvements in reliability and reductions in lubrication costs through condition-based greasing and trending of wear levels, with samples as small as 1 gram. Advantages of preparing substrates with a thin-film grease deposition are discussed for purposes of more streamlined and uniform sample preparation for subsequent analysis. A colorimetric method for evaluating characteristics of new greases, and chemometric methods for evaluating contaminant levels for in-service greases are also discussed. Wind turbines, motors, motor operated valve gearboxes, and robotic assembly examples are given for these cost-benefits, and case studies are shared that demonstrate the return on investment in routine grease sampling and used grease analysis technology.

1. Understanding Grease Flow

One of the most misunderstood aspects of grease lubrication is the flow behaviour of grease within a given machine. This includes the flow from the manual grease gun or automatic luber, through any delivery channel or tubing, to the equipment reservoir, circulation within that reservoir, and final delivery to the bearing, gears or other lubricated components. It might well also include the flow behaviour away from the lubricated component as new grease is added to the equipment.

To gain insight into this behaviour, a study was conducted utilizing a window constructed in an electric motor test stand, so that the movements and thermal profile of the lubricating grease could be monitored during the operation and lubrication process. This was accomplished using the endbell of a Baldor Frame 364T motor, with a 6311ZZC3 bearing. The outside surface of the bearing cap was removed with a saw to expose the bearing reservoir, and in its place, a plexiglass window was installed. The test stand was developed using an NTN 6311ZZC3 double shielded bearing remounted in the modified housing, and fitted with a stub shaft. The stub shaft was sized for the appropriate interference fit mount on the bearing inner race, and was then machined down to a ½" chuck to match the drive motor. This small drive motor was an Emerson ¼ horsepower utility motor, and would allow the bearing to be rotated at the typical 1750rpm when in a normal configuration. It was coupled with a spider insert coupling. [1]

The resulting visual observations were surprising considering the generally accepted concept that grease within an enclosed bearing moves little while in operation, and the bulk of the lubricating is done by liquid oil that separates and seeps into the bearing raceways. Instead, significant grease mobility was observed, which varied as more grease was added, and as the bearing and grease heated up during operation. It was postulated that the movement of grease, a non-

Figure 1: Grease sampler installed in a motor test stand

newtonian fluid, is a function of the applied force (in this case, the movement of the bearing) and the yield stress of the grease. In non-newtonian flow, the yield stress of the substance must be exceeded in order to observe liquid behavior. In the situation of grease in a bearing housing, the yield stress applied to the grease is a function of the distance from the bearing, and the yield stress of the grease also varies with temperature. Therefore, as the bearing heats up, the yield stress of the grease drops, and an increasing percentage of the grease in the housing experiences fluid flow.

Once the grease begins to move, the boundary between fluid flow and non-fluid flow areas of the grease becomes difficult to observe. Knowing this behavior is important in ensuring that grease samples are taken from circulating and representative areas of the housing. To better characterize this boundary condition and the fluid flow/temperature relationship of the grease, modification was made to the test stand to enable observation with an infrared camera.

2. Infrared monitoring of bearing internals during operation

2.1. Test stand setup for infrared monitoring

The test stand described in Section 1 was modified to allow infrared monitoring by replacing the Plexiglas window with a mounting ring, and stretching between the ring and the housing a 1 mil thick polyethylene film. This film was observed with the infrared camera and determined to have a very small effect on temperatures measured during bearing operation due to the high transmissivity of the thin polyethylene. The bearing was hand packed with a polyurea-based grease suitable for electric motor applications, and a small amount of grease was added to the bottom of the housing, as is typical in new installations of this configuration.

While this bearing is typically greased using a hydraulic fitting (Zerk) at the top-most position of the housing, it was determined that adding grease in this manner would cause it to be flung by the movement of the bearing onto the polyethylene film, obscuring the view of the bearing. Therefore, the hydraulic fitting was relocated to the bottom-most position of the housing, which usually serves as the drain point. Other than orientation, these two positions are similar in geometry and proximity to the bearing.

The infrared camera was used to monitor the bearing from startup, and to trend temperature changes observed on the bearing and the grease within the housing. While temperatures were monitored and trended, the purpose of this observation was primarily qualitative in nature.

2.2. Trending of bearing heat up

The bearing was first greased in the normal manner by adding through the hydraulic fitting in the top position, and allowing the grease to fall to the base of the housing, which it can come in contact with the rotating parts of the bearing. This contact typically draws most of the grease into the bearing, with some being flung out and away from the bearing. The thermal trend below shows the general increasing in temperature during this heatup (initially without grease being added) and then the addition of grease marked at about 700 seconds, after the temperature has stabilized.

When grease is added, there are several drops in temperature, which reflect the colder, new grease being placed in the path of the infrared camera. In some cases, this new colder grease is present in the observed pathway (location of the spotmeter) for a longer period of time, which shows as a wider dip. Eventually, these additions of new, colder grease are mixed in with the grease previously added, and the temperature ramp resumes.

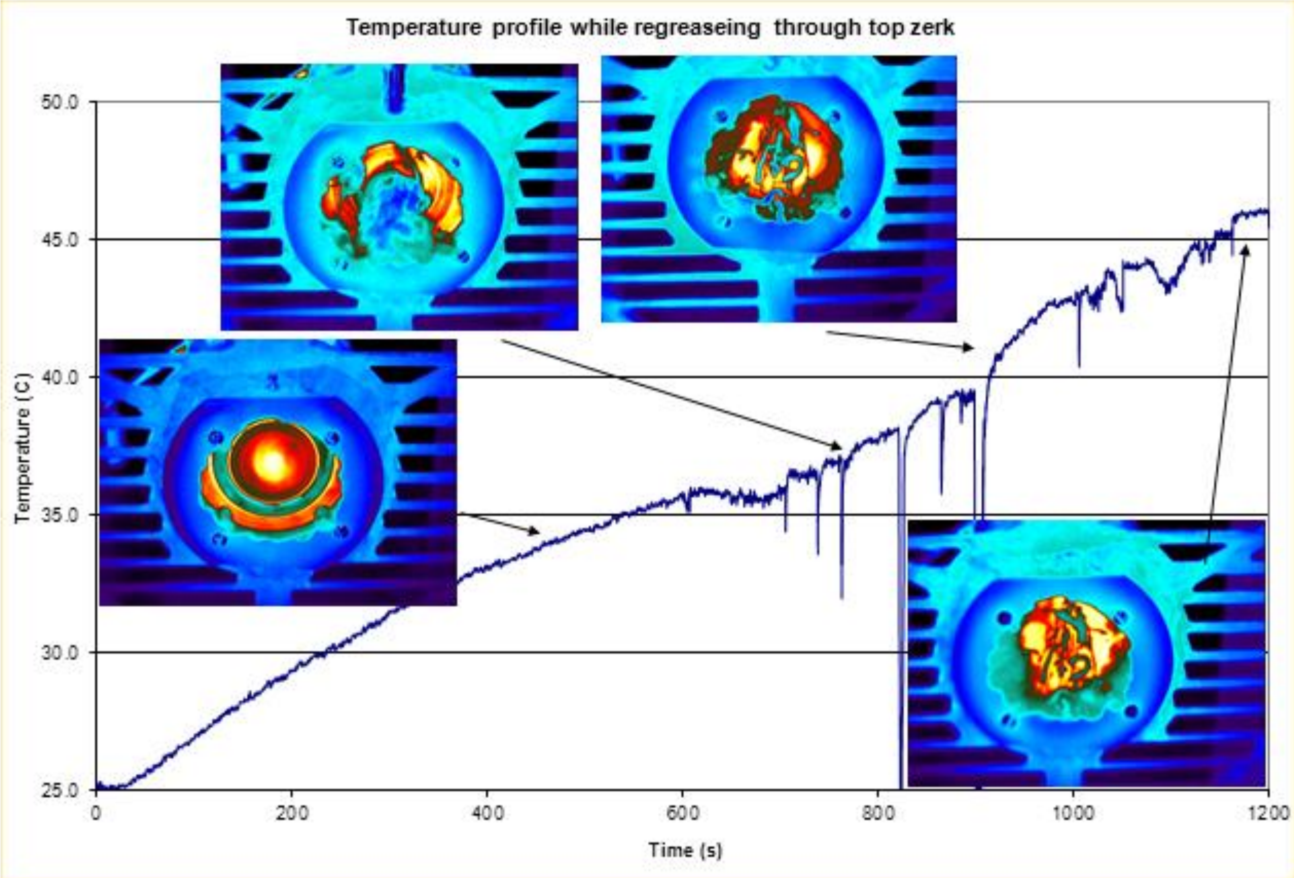

Figure 2: Increasing temperature profile on top addition of grease

2.3. Addition of grease from bottom of bearing

Eventually, grease being flung from the bearing began to cover the polyethylene window, and obscure the ability to observe the behavior of the grease. To prevent this, the drain plug was removed, and the hydraulic fitting was moved to the bottom of the housing, so that grease could be added from this non-typical location. This improved the ability to observe the movement of the grease, and the thermal patterns, but did change the behavior of the grease being added. There tended to be a surge of grease that would contact the moving parts of the bearing, which drew a large chunk of grease into the bearing all at once. This new grease was cooler in temperature than the grease that had already circulated, or was actively circulating. As the amount of grease in the reservoir increased, the area that remained cooler than the surrounding grease increased as well. The profile of the grease temperature, as measured at an area with view of the moving parts of the bearing is shown below in Figure 3.

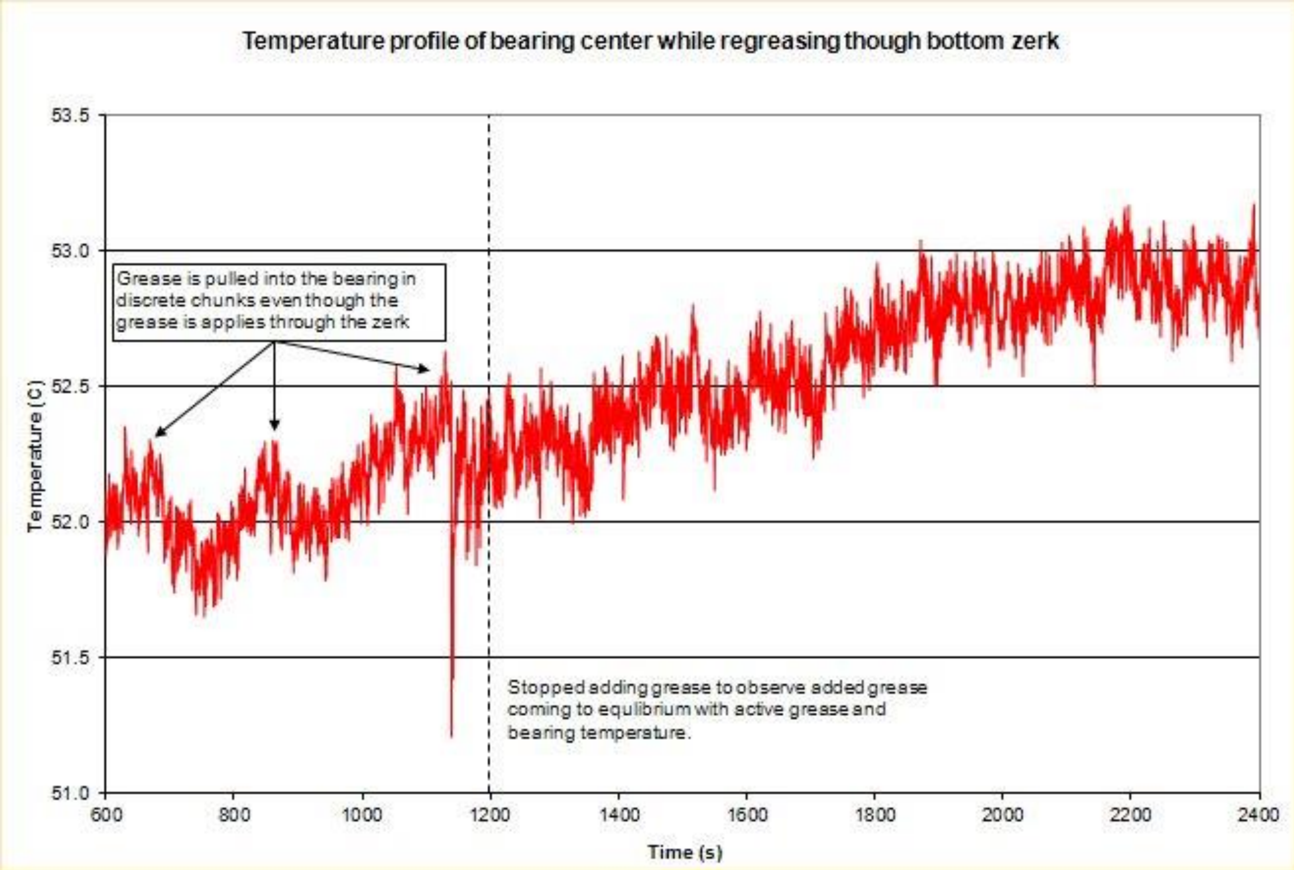

Figure 3: Increasing temperature profile on bottom addition of grease

2.4. Comparison of active zone of grease to newly added grease

Three spotmeters were placed on the bearing to trend the temperatures at the bearing shaft (Spotmeter 1: little or no grease present), in the active grease zone (Spotmeter 2: grease that is actively moving or has just been flung out of the active zone after being in circulation), and the non-active grease zone (Spotmeter 3: newly added grease near the hydraulic fitting. Spotmeters 1 and 2 showed a gradual increasing trend in temperature, consistent with the heat-up of the bearing, and the addition of new grease in viscous churning (viscous temperature increase). Spotmeter 3 showed a trend that first had a spike, when the last added grease was swept into the bearing, giving the spotmeter a view of the warmer grease closer to the active zone in the bearing. Then several pumps of new grease were added, dropping the temperature significantly to the new temperature of the added grease. Over time, this grease, without moving, slowly increased in temperature as it was heated by the surrounding grease, and that portion in active circulation in the bearing. In this test, this demonstrated that slowly, over time, all grease in this housing was influenced by the temperatures and fluid flow of the grease in the active zone.

The findings of this thermal experiment reflect conditions in a new motor which has been properly lubricated with a single grease of the correct type and quantity. In this configuration, the thermal profiles shown demonstrate a tendency for the grease in the housing near the drain hole to be lower in temperature, and sufficiently far away from the applied forces of the rotating bearing to remain in circulation within the housing. This limits the effectiveness of the drain located in this position to provide an adequate drain point for purged grease. Designers of such components, and maintenance personnel tasked with sampling can utilize the thermal profiles shown in this study to adequately position sampling tools, or retrofit equipment with access points that provide grease samples from the active circulating zone of the bearing to enhance monitoring effectiveness. Additionally, any samples taken from this position will likely have spent little time in contact with the bearing, and samples from this position may not reflect the active condition of the grease or the bearing. This information has been utilized to develop accurate methods for grease sampling, including those techniques described in the next section.

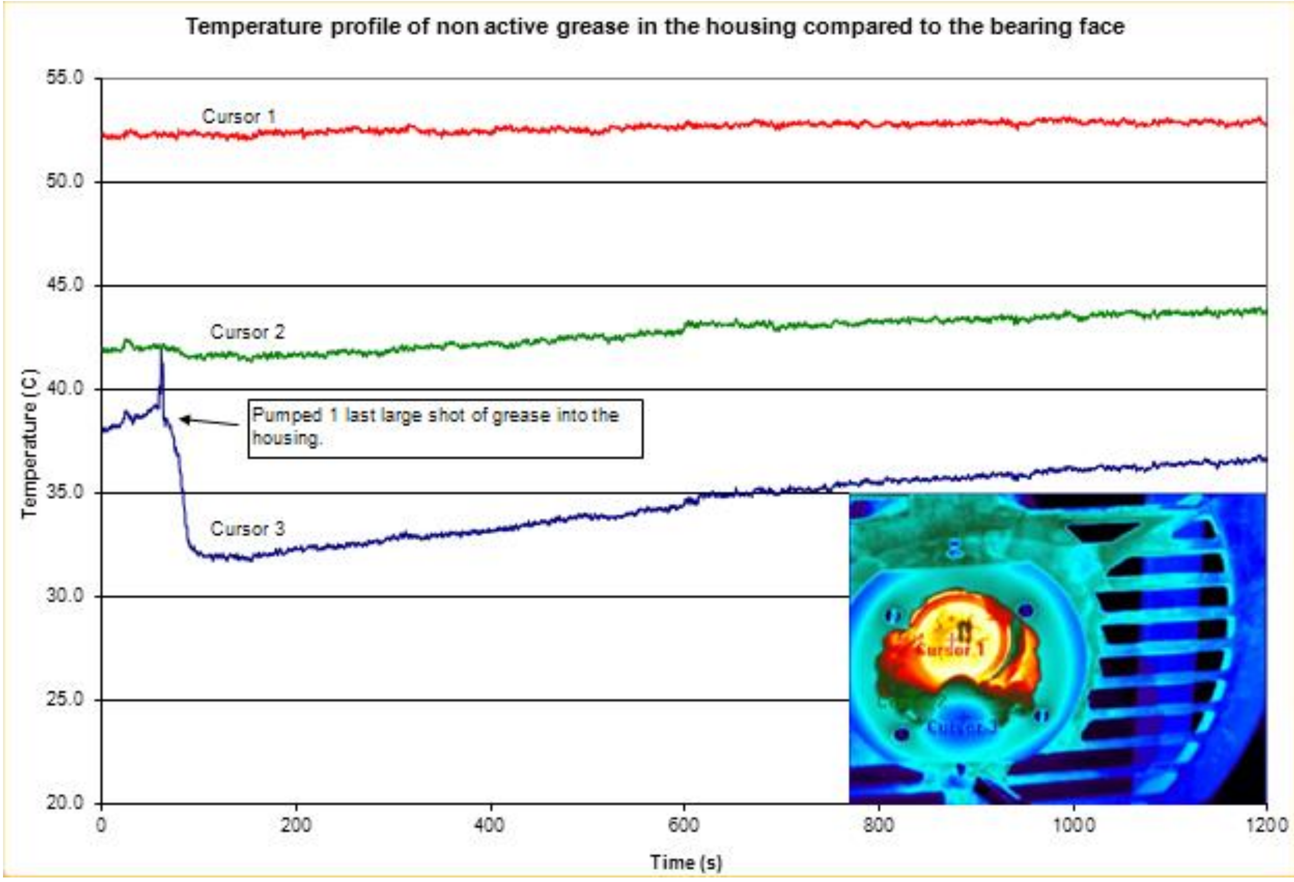

Figure 4: Profile of three selected active and non-active zones in the bearing

3. Obtaining Samples

In most circumstances, procedures for obtaining grease samples from bearing housing and gears are not consistent and likely do not represent the true condition of the "active" grease near the lubricated surface. It may also contain particulate and other contamination picked up during the sampling process. Historically, in-service grease samples from motors, valves, and various bearing housings, typically have required the equipment to be out of service and disassembled. A key factor is that a large volume of sample is needed to perform current analytical testing methodologies and along with this issue is that it is extremely difficult to obtain that representative sample from near the bearing while the component is still in service.

Therefore the challenge in optimising a grease analysis program is the development of test methodologies to measure in-service grease conditions utilizing a smaller amount of grease and a sampling process that enables representative grease samples be taken without disassembling of the component. For motors and certain other components with grease drain paths, new design components are available that allow a replaceable fitting to be installed at the drain port (Figure 5). This fitting serves two purposes. First, it takes the place of a drain plug, allowing displaced grease to drain from the cavity without building up pressure--compromising the bearing shield/seal. Secondly, it provides a protected pathway for representative grease which drains from the cavity to be captured and submitted for analysis.

Figure 5: Passive grease sampling device

In this new design, the sampling fitting is also optimised for the subsequent laboratory analysis. By providing a sealing surface in the fitting cylinder, the entire volume of grease is available for analysis. Extraction of the grease is done under variable pressure and force conditions, and the response of the grease can be measured and related to the grease consistency and flow characteristics, important considerations for in-service greases. As the grease is extruded for analysis, it can be delivered in a thin film for accurate analysis by FTIR, RULER, spectral analysis, and other tests, giving detailed information about grease oxidation, contamination, mixing and wear.

For motor operated valves, gearboxes, and bearings that do not by design deliver grease to a drain point, other sampling tools have been developed. Similar to the principle of a liquid sample "thief", the device must be able to travel from the access hole to the active lubrication location, near the bearing or gear mating area, and bypass the non-representative grease along the way. This requires the device to push grease out of the way in the space between the access hole and the lubricated surface, and then capture a small amount of grease close to the gear surface or bearing grease shear area. Such a device has been developed and tested to demonstrate the capability to deliver a representative sample.

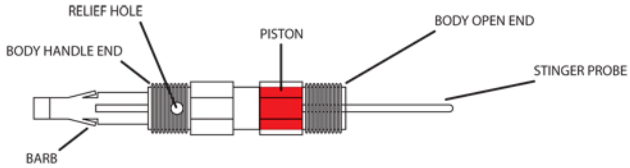

Figure 6: Grease sampler for gearbox testing

The grease sampler is inserted into a t-handle extension to permit remote actuation and capture of the sample at the site of active grease use and wear generation, adjacent to the mating gears or bearing surface.

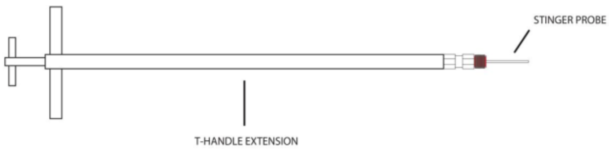

Figure 7: Grease sampler in t-handle extension

4. Grease Wear Testing

4.1. Test stand

Figure 8: Motor Operated Valve (gearbox) test stand

To begin the required analysis for this experiment samples were collected from a Limitorque Actuator in a test stand. Two such valves are utilized in the test stand, MOV-104 and MOV-121. MOV-104 is an SMB-0, and MOV-121 is an SMB-00. The grease samples were obtained by application of a Grease Thief Type II grease sampler with stinger probe and a retractable T-handle tool. The Grease Thief was positioned so that the stinger probe was completely exposed. The Grease Thief and T-handle was placed into an open hole, made available by removing a threaded plug. This port was located on the top of the MOV, directly above the worm or mating pinion gears. After the sample was collected the Grease Thief was cleaned off and capped. After each sample, the MOV was run to the full closed position and then to the full open position, each cycle consisting of an approximately 45 second run of the motor at normal synchronous speed. This allowed for additional grease to return to the section of the MOV that was sampled. For some testing, twenty open and close cycles were performed between samples, but this proved to have little impact on the wear concentration, possibly owing to the lack of gross faults in the tested components.

4.2. Wear Analysis Methods Comparison

To begin the grease analysis the iron concentration was determined by using the FdM+. Each sample was run three times, and the data from them was averaged to obtain a representative measurement. The repeatability of the FdM+ method was extremely good, with moderate variation on the three runs for a given sample (blue trend line in Figure 9). The first five samples were disregarded, to allow for thorough mixing and stabilization of the wear levels. The remaining eight samples were evaluated for comparative analysis against traditional oil analysis debris monitoring techniques.

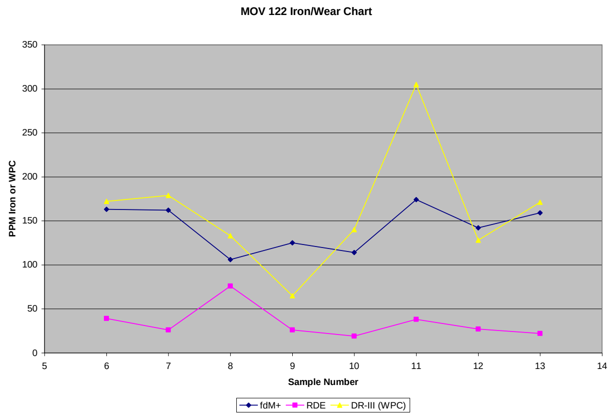

Figure 9: Steady-state wear level comparisons

As the FdM+ values could be directly measured in the sampling device, further treatment was needed to obtain the additional wear results. To prepare the samples for further analysis they were processed by the Grease Thief Analyzer. This instrument extrudes the samples onto a low density polyethylene substrate while determining their consistency. A 0.25 gram sample was weighed out into a 20 mL scintillation vial. A 5 mL portion of a 50:50 mixture of heptane and toluene, grease solvent, was dispensed into the vial. Approximately 5 to 10 glass beads were added to the vial to help break up and dissolve the grease. The vial was then agitated with an orbital shaker for 5 minutes to obtain satisfactory dissolution of the grease. A 10:1 dilution was prepared with filtered blank oil for the DR-III test. To make this dilution, 1 mL of the original

sample was mixed with 9 mL of filtered blank oil in a scintillation vial and agitated for 5 minutes on the orbital shaker. Once the sample preparation was complete, this procedure was repeated for the next portion from this sample. Where sample quantity permitted, three such preparations were made for comparison.
Text.

4.3. Wear Comparison Results

This first graph shows a comparison of ferrous debris measurement techniques from consecutive samples taken from a Limitorque Actuator, a gearbox used in Motor Operated Valves.
The graph (Figure 10) shows the variability seen in the RDE (spectroscopy) and WPC (ferrography) values, which are derived from a weighed portion of the obtained sample. Meanwhile, the FdM+ results are obtained by presenting the entire sample in the Grease ThiefTM in the FdM+ unit. The ability to present the entire sample for analysis without compromising the ability to perform further tests for contamination, oxidation and consistency, provides a more consistent trend of the wear condition.
Statistical analysis of these results are shown in the following table:

Sample #	fdM+	RDE	DR-III (WPC)	Plot Data #
420	163	39	172	6
421	162	26	179	7
422	106	76	133	8
423	125	26	65	9
424	114	19	140	10
425	174	38	305	11
427	142	27	128	12
428	159	22	171	13
Average	143.1	34.1	161.6	
StdDev	25.4	18.3	68.5	
RelStdDev	17.7	53.7	42.4	

Figure 10: Statistical Analysis of grease wear monitoring technologies

The relative standard deviation value for the FdM+ shows much greater consistency in the samples. To further evaluate the reasons for this, and to test for variability in ferrous debris concentration through a given sample, a selected number of samples in a separate experiment, again from a Limitorque gearbox, were extruded to prepare several analyses for each 1 gram sample from a grease thief. The relative standard deviation was then calculated for the RDE and WPC values to demonstrate the variability seen in a single sample when analyzed in three separate sections.
The results indicate a difficulty in obtaining trendable values for ferrous grease wear when employing methods that require dissolution of a portion of the grease sample and analysis of the liquefied sample in typical oil analysis instrumentation. This is due to the non-uniformity of distribution of wear in a grease sample, and the difficulty in achieving a uniform dispersion of that wear. Particle size limitations of those methods are similarly a concern. However, when utilizing a method that counts the entire ferrous content of the sample, this variation is minimized, and a more valid trend can be developed for samples from a given location. In any case, the challenges of obtaining samples that represent the condition of the monitored component remain, and must be addressed satisfactorily to obtain actionable data on the wear condition of those components.

Figure 11: Hall-effect (FdM+) sensor and Grease

4.4. Wear Trending Test

In 2009, an EPRI project was initiated on greases that included testing the validity of the sampling method. This involved the construction of a test stand using SMB-0 and SMB-00 actuators from Progress Energy. Testing included fiber-optic inspections of operating actuators to observe the movement of grease that had been in service for several years in a power plant environment. This testing demonstrated the movement and mixing of grease that still maintained a consistency close to its original value.

Other testing was performed to confirm the ability to develop consistent trends in wear levels, utilizing the Grease Thief geometry, and a Hall-effect sensor (Figure 11) to determine total ferrous wear content, in parts per million (ppm), for a given grease sample. In order to determine the ability to show trend changes in wear levels for known increased wear conditions, the SMB-00 actuator was deliberately misaligned. One hundred cycles of 90 seconds each were performed to first gather a stable baseline for total ferrous wear. Then shims were installed on one side of the motor mounting to induce a pinion gear misalignment and generate increased wear levels. 200 additional samples were taken in this misaligned condition, which showed a clear and significant increase in the wear trend (Figure 12) to confirm the increase generation of wear, and the ability of the Grease Thief sampler and Hall-effect sensor to obtain representative data for this excessive wear condition. These studies were published by the EPRI NMAC center in the Effective Grease Practices guide.

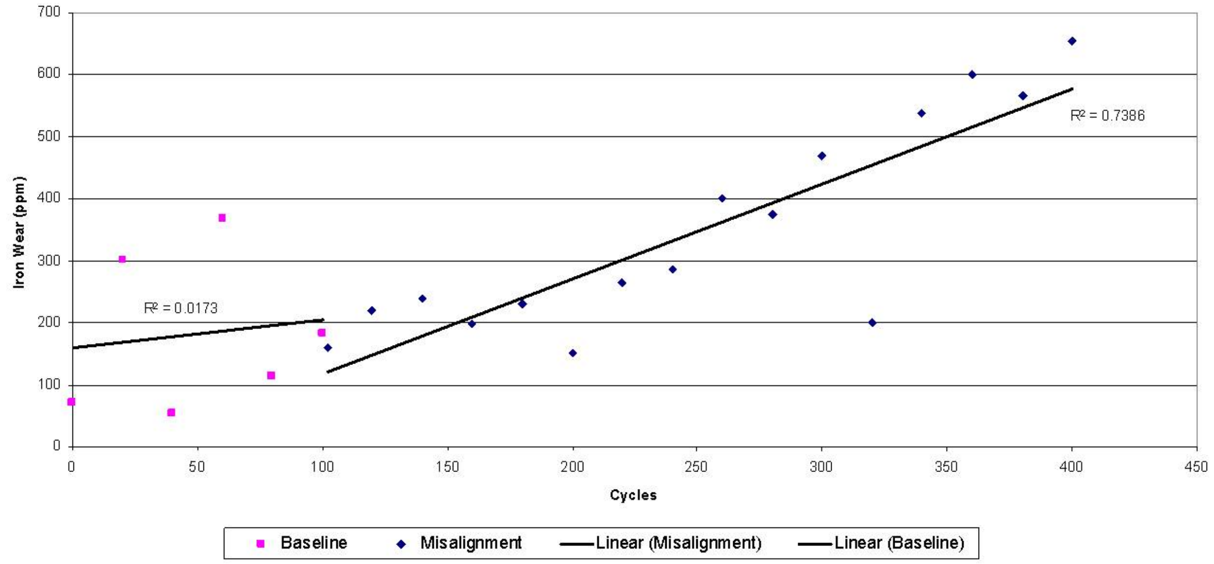

Figure 12: Increase in wear rate on pinion misalignment

5. Basic Analysis Options for Grease

The following tests make up a streamlined grease analysis process that takes advantage of the previously described sampling fitting. This allows the first two tests to be performed as part of the preparation of the sample for the subsequent tests listed. This reduces that amount of sampling handling and preparation required, and thus the potential costs of performing a meaningful and routine grease analysis for critical equipment.

5.1. Ferrous Debris Monitoring

A difficulty in evaluating wear particulate in grease exists because of the inability to agitate a sample to evenly distribute particulate, as is done with oils. This non-uniformity of distribution can lead to misleading results because the portion of the sample selected for dissolution and analysis may be skewed higher or lower with respect to wear particle content. One way to compensate for that condition is the use of a Hall-effect sensor to measure the entire ferrous content of the obtained sample. When using the sampling fitting described in Section 3, the entire volume of grease can be measured in a ferrous debris monitoring device that includes a chamber surrounded by the sensing coil. This method minimizes data scatter due to particle distribution issues and improves trendability and sensitivity of results.

5.2. Grease Consistency

By measuring the load under varying conditions during the extraction of the grease through the extrusion die, the consistency of the grease can be compared to the new grease consistency. Changes in this value, whether indicating a thinning or thickening of the grease, can be used to flag this property. Followup detailed analysis with a rheometer can further classify the condition of the grease and relate to such parameters as dropping point and cone penetrometer, based on earlier studies by Nolan and Sivik [1] and Johnson [2]

5.3. Comparative FTIR Spectroscopy

FTIR spectra are created from new grease samples for all greases in a facility's program. Using a horizontal attenuated transverse reflectance (HATR) rig, a thin film of grease is applied across the crystal, and the auto-gain function is used to maximize signal and get a representative spectrum. Then the sampled in-service greases are tested and compared to the spectra of new grease. In particular, for different families of greases, the FTIR spectra are quite different and can be compared to see if significant mixing has occurred. In other cases, similar greases (two different polyurea greases) might not have significant differences in their spectra, but there is less likelihood of compatibility issues in that case. Still, many greases within the same family from different manufacturers can be differentiated with FTIR analysis. Also this test is valuable in monitoring for grease oxidation and the presence of certain organic additives. The Grease Thief substrate also holds value as a disposable IR sample cell, where the automatic preparation with the die extrusion process will speed the preparation and cleanup process, and further reduce costs associated with analysis.

5.4. Anti-Oxidants

The RULER instrument works on the principle of linear sweep voltammetry. By applying this test method, in which a variable voltage is applied to the sample while measuring the current flow, the presence and concentration of various antioxidant additives (including, but not limited to ZDDP) can be determined based on their unique electrochemical oxidation potential and the magnitude of the induced current. Monitoring residual anti-oxidants in purge greases can provide feedback on the effectiveness of grease relubrication frequencies. For example, a grease sample that has been purged from a bearing on the established relubrication interval, when analysed and determined to have a large amount (perhaps 70% or more) of residual anti-oxidants, and also shows good consistency characteristics, may be a candidate for extension of relubrication interval. Conversely, a purge grease sample that shows no or minimal (less than 25%) residual anti-oxidants may not be completely protected from oxidative stressors during the grease life-cycle, and may appropriately be adjusted to a shorter relubrication interval.

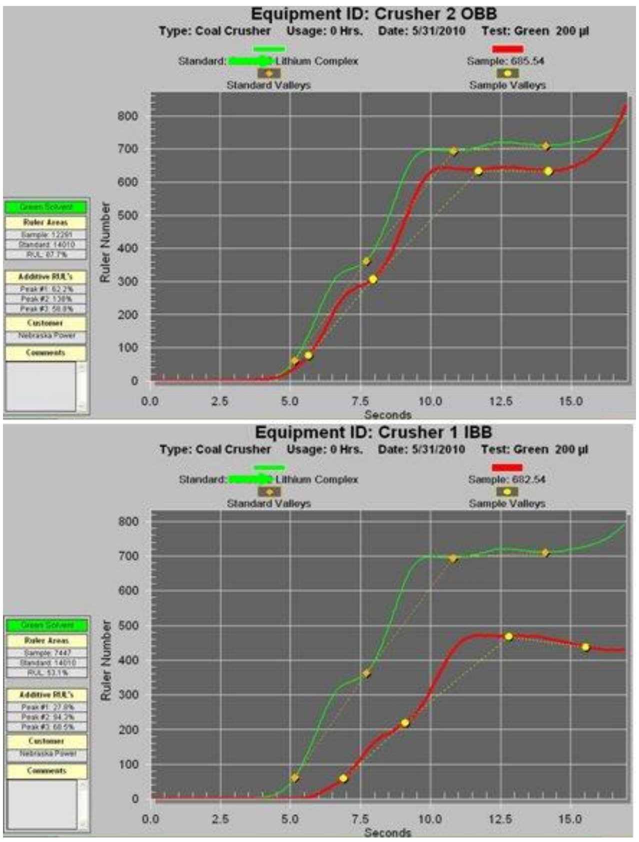

Figure 13: RULER test to evaluate two greases from similar operating equipment, with the lower showing more rapid loss of anti-oxidant

5.5. Metals Spectroscopy

The grease is weighed out and added to a glass vial where it is diluted and dissolved with a filtered mixture of grease solvent. This liquid mixture is then analyzed by RDE (Rotating Disc Electrode) or ICP (Inductively Coupled Plasma) spectroscopy, and the results are ppm normalized to 1 gram of grease based on the measured weight of grease that was dissolved. The concentration of metals in the grease can be compared to the new grease for the purpose of identifying significant differences in additive metals that could point toward grease mixing. Also, the presence of wear metals can be deduced.

5.6. Grease Colorimetry

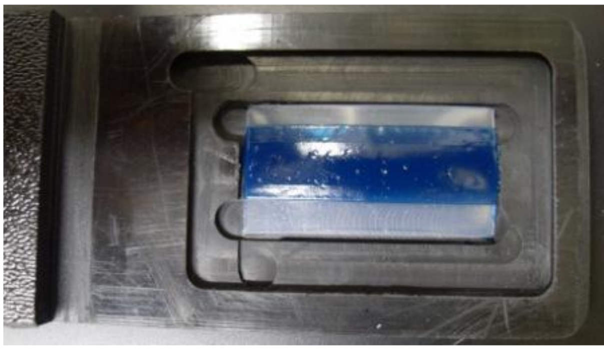

Figure 14: Spectrometer and optical cell for grease colorimetry

Visual observations of grease appearance are a common assessment tool for field evaluation of lubricated components. Appearance changes including darkening and unexpected or mixed colours are often the first condition noted that may indicate unusual lubrication conditions or mixing. A desire to empirically evaluate and substantiate such observations led to the development of an optical cell, used to present a grease sample in a uniform manner for subsequent visible light spectral analysis (Figure 11). This grease colorimetry optical cell is designed to create an optical path for the i-Lab visible light spectrometer, and includes a sliding drawer that presents the extruded grease thin-film on substrate produced from the Grease Thief die extrusion method. The resulting 0.040” (1.0 mm) pathlength is backed by a polished stainless steel mirror, which allows testing of the grease in a uniform manner without interference from ambient light and without contacting the grease sample.

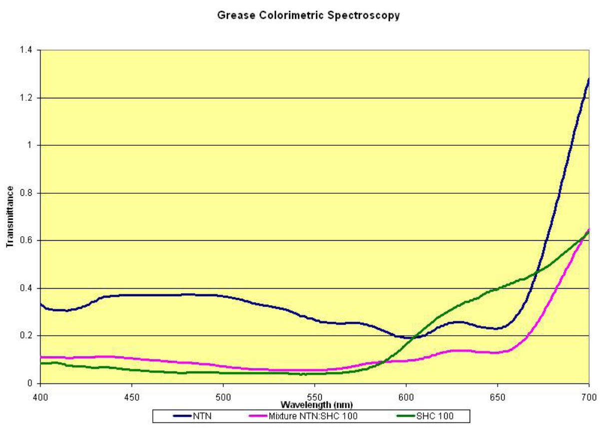

Figure 15: Colorimetric comparison of two greases, and a suspected mixture

The analytical result is a vector representation of the colour, in chromaticity and brightness. Also, a full spectral response of the grease in the 400-700 nm range is represented (as seen in Figure 15). This allows a qualitative comparison of grease colorimetric spectra to include as a data point to evaluate the likelihood of a used sample having constituent contributions from among some likely new greases.

The use of grease colorimetry as a chemometric method for determination of the quantity of a known particulate contaminant was evaluated. Figure 16 shows a series of spectra derived from the addition of a known quantity of coal dust. In an environment where grease is exposed to this contaminant, especially greases that are in storage or otherwise not substantially affected by other colour modifying influences, the method may be useful in quantifying these contaminants and comparing against guidelines for contaminant content limits.

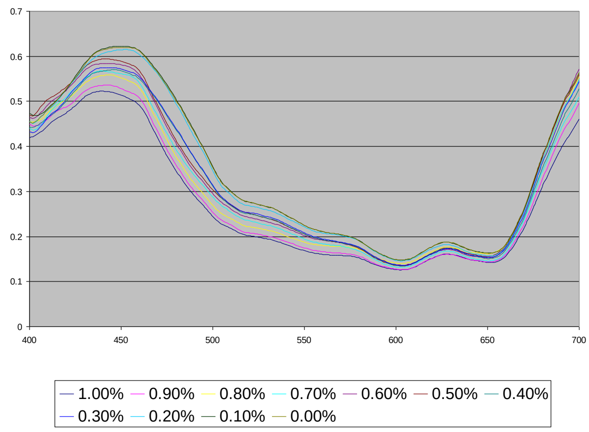

Figure 16: Spectral graphs of a grease with increasing quantity of dispersed coal dust

It has been suggested that grease colorimetry may have value in the manufacture of greases. Current commercial greases typically are dyed, for differentiation and marketing purposes. The specific colour of a grease becomes closely identified with the brand, and maintaining consistency in the colour of the product, while not affecting performance, may be important from a perception standpoint. Batch testing of greases by comparing an in-process batch with a colorimetric profile may enable grease manufacturers to quantitatively evaluate colour and include a quality control step on appearance as part of the process.

6. Data Integration and Advanced Analysis

Together, these tests can be used to evaluate the condition of the grease, determine the extent of mixing with an incorrect grease, detect oxidation, measure the depletion of anti-oxidant additives, and categorize the extent of wear present in the sample. These tests can be done cost effectively because the consistency measuring instrument prepares the grease as a thin-film substrate for weight normalization and easy dissolution of the grease thickener, so the liquid sample can be analyzed with typical oil analysis equipment.

6.1. Additional Testing

If concerns arise during the above trending and screening process, follow-up analysis can be performed using the following tests:

Analytical Ferrography

This test can also be performed on the dissolved grease (prepared as for metals spectroscopy) to visually identify the amount, shape, composition, and wear severity of the particulate in the sample. This method and its benefits are well documented for oil analysis, and have similar benefits for properly obtained grease samples. The key difference for greases is that it is necessary to understand that wear levels are cumulative during the operating life of the grease, and that relative quantities of observed particulate can be misleading, if comparing samples with significant differences in service time for the grease.

Patch Microscopy

When the particles of interest are non-metals or non-ferrous metals, there may be some advantage to preparing a Millipore patch by drawing a diluted sample under vacuum through the patch and microscopically analysing the particulate content to identify the presence of wear or contaminant particles, and relatively quantifying their presence. Often, this test is more difficult with greases than oils, because of the difficulty in completely dissolving grease thickeners sufficiently to pass through the patch. Solvent selection is critical, and some grease thickener types do not perform well in this test, with the presence of thickener fibers dominating the filter patch and obscuring other particulate.

Grease Rheology

Use of a rheometer and evaluation of such parameters as normal force measurement and apparent viscosity can be significant in the characterization of grease properties. Prior research [1,2] has indicated the value of applying rheological measurements to both new and used greases, and research is ongoing to optimise this analysis and relate measured parameters to changing physical properties. Rheological measurements provide insight on changes due to incompatible grease mixing, excessive grease working, and severe oxidation. One of the capabilities of this testing is the ability to evaluate the compatibility of mixed greases. In Figure 17, a mixture of two NLGI Grade 2 greases shows an oscillatory stress value of 142 Pa. However, the baseline for the grease designated for this application, seen in Figure 18, has an oscillatory stress of only 81 Pa. This 80% increase represents an unacceptable change in the properties of this grease and shows that they are not compatible in this application. The data results of this test provide insight into grease pumpability, shear characteristics, and the tendency for a given grease or grease mixture to undergo “channeling” or “tunneling” in bearing and gear applications.

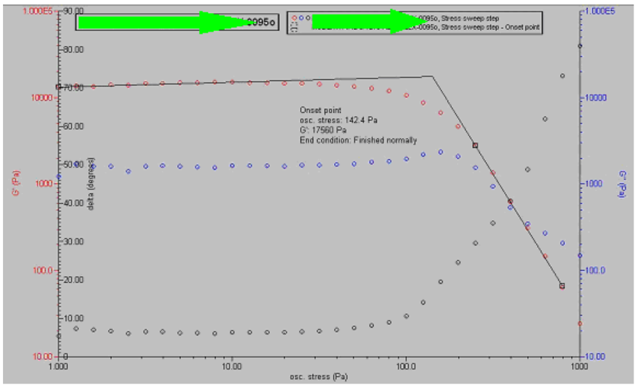

Figure 17: Oscillatory stress measurement of mixed greases with cone and plate rheometer

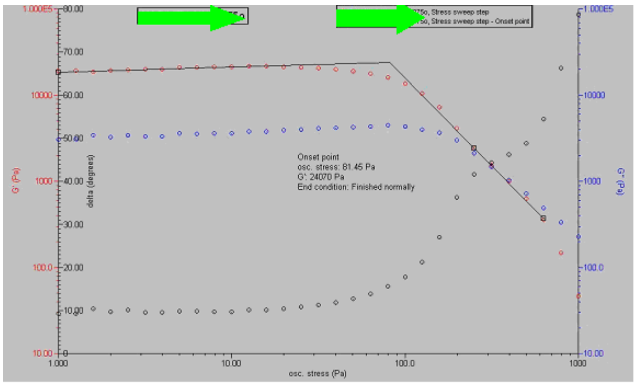

Figure 18: Oscillatory stress measurement of reference grease with cone and plate rheometer

7. Wind Turbine Applications

Wind turbines are part of a growing industry of renewable energy. Certain regions of the globe are particularly suited to deploy wind turbines to capture this energy source, and they are appearing in ever growing numbers. Much of the focus to date has been on the transmission gearbox, an oil lubricated speed increaser that takes the relatively slow rotational speed of the turbine blades and converts it to a sufficiently higher speed for the generator. While it is appropriate to focus on the transmission, it is by no means the only lubricated component where reliability is a concern.

There are no fewer than 6 major grease lubricated components in the majority of large wind turbine designs currently dominating the market. They include two grease lubricated gearsets, the pitch drive gears and the yaw drive gears, as well as the main bearings, generator bearings, pitch bearings and yaw drive bearings. For each of these grease lubricated components, failure to function can either interrupt completely, or significantly impact the efficiency and capacity for electric generation. Therefore, a solution to the grease sampling and analysis challenges present in the wind turbine can have a significant financial impact through the early detection of abnormal wear, or the identification of degraded or contaminated grease lubrication.

For open gears, the collection of a sample is best accomplished with a kit that utilizes a spatula-like tool to enable the sampler to gather the grease from the gear teeth. Since one of the important considerations is a streamlined analysis process to ensure cost-effectiveness, the gathered sample is transferred to the grease sampler device that has been described, by means of a simple syringe. Because a non-newtonian fluid like a grease can be difficult to move under vacuum (may be insufficient to reach the yield stress for flow), the syringe plunger is removed from the body by completely pulling the handle back and out, and the open body is packed with grease using the spatula. The plunger is re-inserted, and the grease can be easily moved while under pressure, to fill the grease sampler. The laboratory will now have a standard geometry, sample size and presentation for the streamlined analysis techniques described earlier.

For bearing locations, the same spatula kit can be used, or for enclosed locations with a sufficient access hole, a second type of sampler with a long-handled extension tool may be even more effective. This device allows the device described in Figure 5 to be inserted into the T-handle as shown in Figure 6. A drain or access plug is removed, and the assembly is inserted either a set distance into the opening, or until the stinger probe on the front of the fitting contacts the bearing surface.

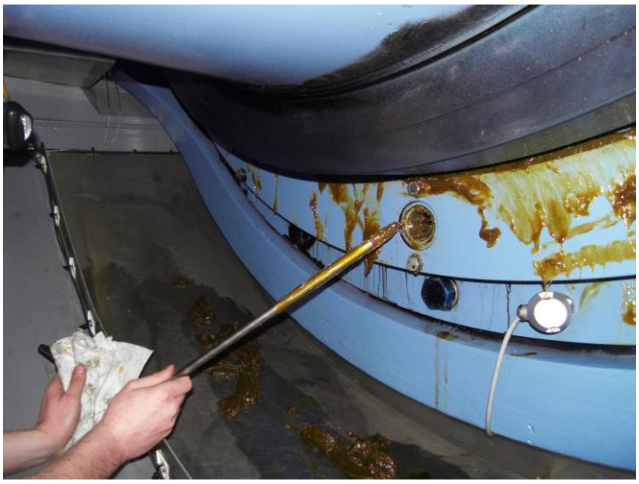

Figure 19: The full Grease Thief is removed from the drain of a 2MW wind turbine, and can be submitted for streamlined routine analysis for grease and bearing condition assessment. (Oelcheck Labs, Germany)

The sample can then be cored from this location by sliding the outer tube forward, providing a sample that is close to the wear generation surface and avoid collecting grease which may not be representative of the current wear condition, or the condition of the grease currently providing lubrication to the bearing.

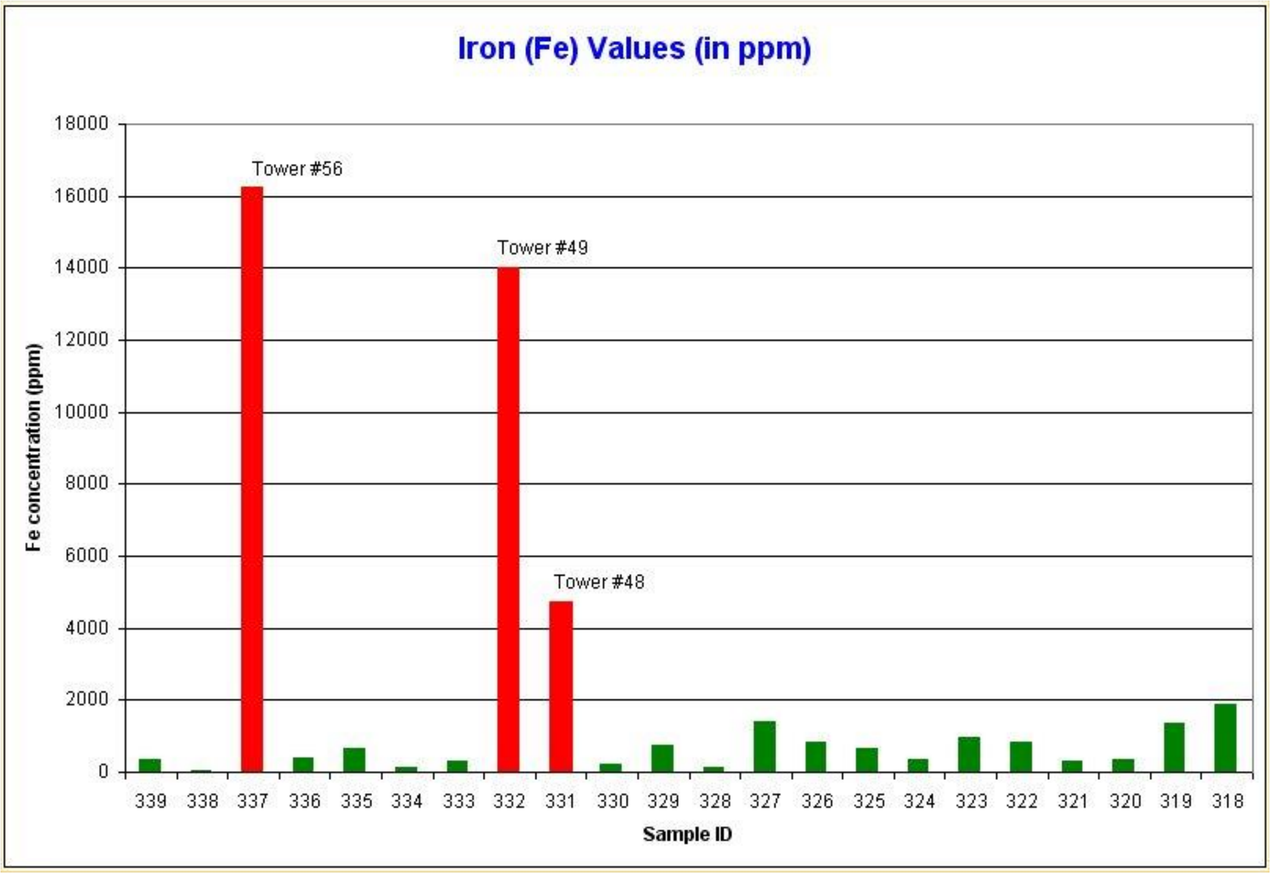

Figure 20: Graph of ferrous debris levels in multiple wind turbine main bearings, indicating abnormally high wear levels in three of the turbines in this farm.

With these new methods, reliable samples and cost-effective analysis solutions will provide insight into the operational condition of the critical grease-lubricated components of the wind turbine, and contribute to a condition-based maintenance strategy, as well as opportunities to diagnose and correct degradation root-causes to extend and optimize the life of wind turbines.

8. Other Applications

In addition to the gears and bearings in the Wind Turbine applications, other applications also provide potential for cost benefits through routine analysis. Robots have, in recent years, been playing an ever expanding role in manufacturing, ranging from small, precise parts placement and assembly, to larger payloads and activities, including automotive applications. Some automotive manufacturers have sought to develop methods to evaluate grease sampling and analysis methods for suitability of monitoring these robots that can have a significant impact on reliability. Periodic sampling and analysis of the grease from these components can provide the robot owner with a clearer picture of robot joint health, and pinpoint latent issues that can be planned and addressed prior to failure.

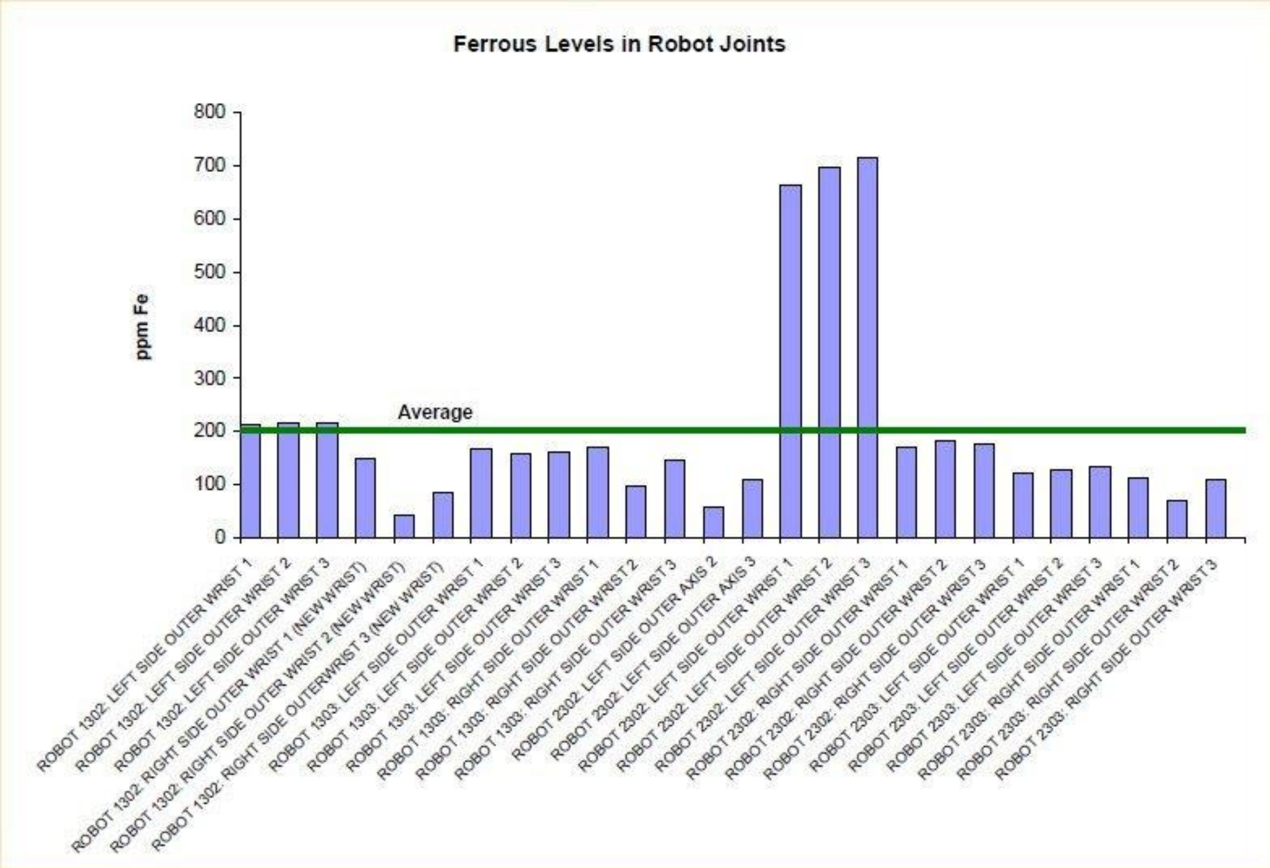

Figure 21: Graph of multiple robot drive joints, indicating abnormally high wear levels in one robot.

Additionally, monitoring of grease condition, through anti-oxidant and consistency trending, may allow an owner to transition from calendar-based to condition-based grease changeouts. This has the potential to save hundreds of thousands of dollars per year for a large auto manufacturer. Grease sampling and analysis may be a solution to address greased component reliability, to avoid unexpected failures, identify emerging problems, and even intervene to correct potential problems before significant damage occurs. This is especially important for manufacturing applications where unexpected downtime has a significant economic impact.

Figure 21 shows a series of samples taken at multiple locations from several robots, and then analyzed for ferrous wear content. It becomes quickly clear in this example that three locations from one robot bearing clearly require attention, and may indicate abnormal wear from that gear, requiring intervention to avoid failure.

Motor Operated Valves (MOVs) are found in multiple industries, but are perhaps no more closely monitored, nor are exceeded in investment in maintenance per unit, than in nuclear power plants. These critical units play an important role in containing nuclear materials within the plant, and responding to abnormal conditions to maintain proper cooling conditions in the reactor core. The MOVs include greased components in the gearbox, stem-stem nut, motor (usually sealed), and in the limit switches. Proper sampling and periodic monitoring of these sampled greases can greatly improve reliability of these components.

In order to evaluate the ability to detect latent wear issues in an MOV gearbox, an accelerated wear condition was created by deliberately misaligning the drive motor to the gearbox driven gear. The resulting samples taken with a fitting and T-handle showed a clear change in wear rate, as evidenced by the change in slope of the samples shown previously in Figure 12.

With confidence in obtaining a representative sample, and one that trends up with increasing wear generation, lends confidence to this sampling method, provides insight to changing wear conditions, and provides additional analysis results for evaluating for grease mixing, presence of contaminants, changes in consistency and flow characteristics, and remaining useful life of the grease through residual additive trending.

9. Conclusion

Grease analysis presents a significant opportunity to expand machinery diagnostic capabilities. The historical challenges of obtaining representative and trendable samples are being addressed through technological developments and new approaches. The further development of repeatable analysis methods that utilize smaller quantities of grease will produce greater value, and encourage the sampling of greases from locations where reliability is important. By designing grease sampling equipment appropriately, the matter of optimal grease replenishment may also be addressed through the establishment of sampling programs. Infrared thermography has played an important role in understanding the flow dynamics of grease within a machine internals, and thus the selection of the proper location and method for grease sampling. Infrared also is complementary to grease analysis when comparing lubricant and machine conditions seen in grease analysis to thermal patterns observed at the machine surfaces with Infrared Thermography. Wherever there is a critical machine, regardless of lubricant type, the demand for reliability drives the development of improved sampling methods and analysis techniques to produce the valuable information present in lubricant analysis. The integration of multiple diagnositic technologies, such as Infrared, Vibration Analysis, Motor Circuit Monitoring, and Lubricant analysis (both oil and grease) is a proven best practice approach to improving machinery reliability and getting the most from investment in diagnostic monitoring.

List of References

[1] Nolan, S., Sivik, M., "The Use of Controlled Stress Rheology to Study the High Temperature Structural Properties of Lubricating Greases," NLGI 71st Annual Meeting, Dana Point, CA, 2004.

[2] Johnson, B., "The Use of a Stress Rheometer in Lieu of Cone Penetration," NLGI 74th Annual Meeting, Scottsdale, AZ, 2007.

[3] Wurzbach, R., "Streamlined Grease Sampling and Analysis for Detection of Wear,Oxidation and Mixed Greases", NLGI Annual Meeting, Williamsburg, VA, USA, June 2008.

[4] Wurzbach, R., Williams, L., Doherty, W., "Methods for Trending Wear Levels in Grease Lubricated Equipment", Society of Tribologists and Lubrication Engineers (STLE) Annual Meeting, Las Vegas, NV, USA, May 2010.

[5] Electric Power Research Institute, "Effective Grease Practices", Report #1020247, Palo Alto, CA, USA, October 2010.

[6] Wurzbach, R., Bupp, E., Hart, J., "New methods of grease sampling and analysis for motor operated valves", Motor Operated Valve Users Group Conference, San Antonio, TX, USA, January 2011.

[7] Wurzbach, R., Williams, L., Bupp, E., "Grease Sampling and Analysis for Wind Turbines and other Bearing and Gear Applications", ReliablePlant Conference, Indianapolis, IN, USA, May 2012.