WHITE PAPER

LASERNET FINES® Q200 – A SOLUTION TO OIL ANALYSIS INCLUDING PARTICLE COUNT AND PARTICLE SHAPE CLASSIFICATION

Spectro Scientific

Synopsis

This paper describes how using the state-of-the-art LaserNet Fines® (LNF) Q200 instrument in your lab provides an accurate, cost-effective solution to traditional methods of analyzing oil debris particles. LNF offers a "one-stop shopping solution" to identifying the type, rate of production, and severity of mechanical faults by measuring the size, distribution, rate of production, and shape features ("silhouettes") of wear debris in lubricating oil. No longer are highly trained human analysts and time-consuming calibration procedures at specified flow rates required to obtain accurate particle counts and particle shape classification.

The focus of this paper is to provide details on how the LNF operates and how its method of particle counting and optical image analysis compares to laser style particle counters and traditional analytical ferrography. Finally, two cases studies, one for an Engine Test Cell and one for a Gearbox Accelerated Failure test, are discussed in the paper to demonstrate how the LNF technology offers unique active machine wear results, without the qualitative subjectivity and potential cost of traditional ferrographic analysis.

Introduction

LNF Technology

Jointly developed by Lockheed Martin and the Naval Research Laboratory with the Office of Naval Research, LNF is a particle shape classifier that also provides a highly accurate particle count for particles greater than 4 µm using laser imaging techniques and advanced image processing software. Silhouette images of all particles larger than 20 µm in major dimension are automatically classified into the following categories:

- Cutting
- Severe sliding
- Fatigue
- Nonmetallic
- Fibers
- Water droplets

The instrument counts these particles and provides a quantitative measure of active machine wear. Bitmap images are saved and printed on report for review. Reliability engineers can make more informed decisions using LNF data by trending both the total particle size distribution and the sub category particles. In addition to solid particles, the percent of free water is estimated based on the calculated volume of the detected water droplets greater than 20 µm while air bubbles greater than 20 µm are recognized and eliminated from the count. The instrument automatically corrects for the color of the fluid, making it accurate for intrinsically light and dark-colored fluids such as in service engine oils.

The role of IR spectrum analysis

The basic operating principle of LNF is illustrated in Figure 1 below.

1. A representative oil sample is drawn from the lubricating system and brought to the unit.
2. The oil is drawn through a patented viewing cell that is back-illu minated with a pulsed laser diode to freeze the particle motion.
3. The coherent light is transmitted through the fluid and imaged onto an electronic camera.
4. Each resulting image is analyzed for particles.

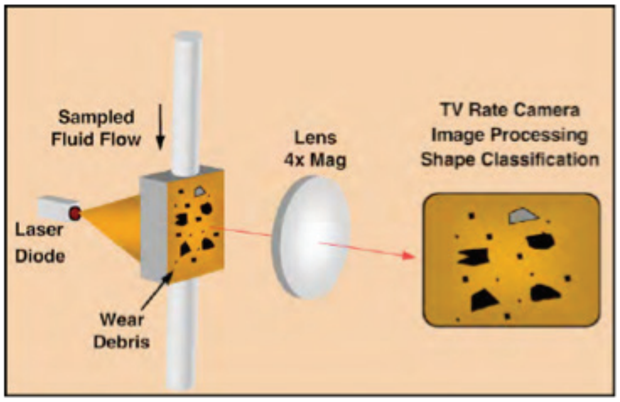

Figure 1: LaserNet Fines® Operating Principle

For wear particles in lubricating oil, the instrument displays particle size in terms of maximum chord. For particles in hydraulics, it displays the size in equivalent circular diameter for compatibility with ISO cleanliness codes. In either fluid, shape characteristics are calculated for particles greater than 20μm, and the particle is classified into either a wear category or contaminant category.

Classification is performed with an artificial neural network developed specifically for the LNF system. Shape features were chosen to provide optimal distinction between the assigned classes of fatigue, cutting, severe sliding, non-metallic particles, fibers, water bubbles, and air bubbles (Figure 2). An extensive library of particles, which were identified by human experts, was used to train the artificial neural network.

The next sections compare how LNF gathers and analyzes data compared to Optical Particle Counters and then traditional ferrography methods.

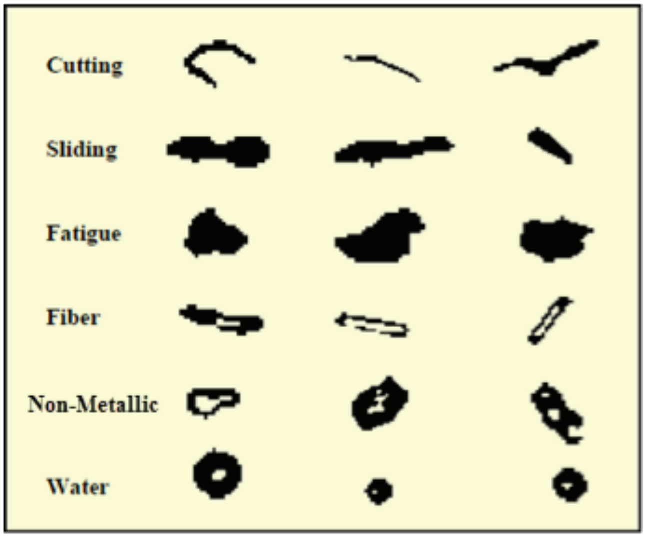

Figure 2: Examples of Particle Class Morphology

2. LNF Compared to Optical Particle Counters

LNF performs the same function of traditional laser particle counters and also performs analytical ferrography tasks. LNF uses a two-dimensional sensing array (640X480 pixels) while the particle counter uses a one-di-mensional array. This added spatial diversity allows LNF to examine much higher particle concentrations without special sample preparation in addition to extracting particle morphology. With the ability to recognize shape, the particle counts of LNF are not contaminated by the presence of air bubbles or free water. Instead, those items are both subtracted from the debris counts, with the free water fraction identified separately. The remaining wear debris and filter fibers are included in the total counts and also display in their own distributions.

There are three primary problems with the method existing laser-based particle counters use to determine the size of particles:

- First, they use a point source detector instead of the LNF instrument's two dimensional detector. It is like counting cars on the side of a multi-lane highway. Overlapping particles will be counted as one bigger particle and skew the final distribution.
- Second, the particle counters must be calibrated and used at a specified flow rate. The accuracy of the detection channels rely on a known flow rate for proper counting and for determining the total sample volume. The LNF detector is highly immune to flow rate variation because it freezes particle motion with a short laser pulse. Sample volume is known from the fixed dimensions of the viewed volume and the number of frames processed.
- Last, traditional obscuring laser particle counters misrepresent the size of nonmetallic particles (e.g. silica, dust) because these

particles can appear to have translucent centers (see Figure 2 above) at the wavelengths the laser uses. LNF uses image processing to "fill-in" the translucent centers before calculating the particle's equivalent circular diameter, therefore accurately reporting the size of oxides and other semi-translucent dust without special calibration.

LNF does not require calibration with a Standard Reference Material because the measurement accuracy is intrinsic to its configuration. Its particle size measurements rely on the camera's pixel size and the magnification power of the optics – both are fixed elements which remain virtually unchanged over time. The measurement volume relies on those fixed elements and also on the thickness of the viewing cell, which is also fixed and does not significantly change with time or operating temperature.

The most common question regarding the LNF is: "How well does LNF correlate with laserbased, optical particle counters (OPCs) on the market?"

If the samples are properly prepared, LNF particle counting results will correlate to conventional particle counters, with the following notes:

1. LNF can count heavily contaminated samples (>5M particles/ml) without dilution, while for conventional particle counters it is very difficult to count such dirty samples (the samples have to be very heavily diluted).
2. The upper size limit for LNF is 100µm (the flow cell path as well as the pore size of the screen filter). However, laminar flow coupled with the large aspect ratio of some particles means that particles >100µm can also be reported, such as for fibers and hair while in some legacy reports, counts of particles of 250 µm were reported using conventional particle counters.
3. When interfering soft particles are present in the oil (such as water droplet, silicone particles from anti-forming additives), correlation between LNF and conventional particle counters is difficult.
4. Interference from soot up to 2% without the need for dilution.

3. LNF Compared to Traditional Ferrography

Ferrography has long been the standard method for determining the type of wear mechanisms and severity of faults in lubricated machinery. Here are four primary drawbacks of traditional ferrography:

- First, the test is time consuming. Because of this, Ferrography is often performed on a case-by-case basis. Results from other tests like RDE and LNF are used to screen for a Ferrography test.
- Second, to achieve meaningful results a trained analyst is required.
- Third, the ultimate result is strictly qualitative. Each analyst has their own methodology and preferences for analyzing a prepared slide. Even though most oil analysis labs diligently train their analysts to think the same, inconsistencies are still present and even more obvious from lab to lab. This is where LNF bridges the gap, providing sample to sample screening insight into possible wear mechanisms and fault severity in a fraction of the time and without the need for a highly trained analyst. LNF counts and classifies all particles in its viewing cell to provide quantitative, repeatable measurements useful for trending and the early assessment of machine condition.

Figure 4 below compares Analytical Ferrography with LNF according to various analysis factors.

	ANALYSIS TIME (VOLUMN)	FLUSH TIME	COINCIDENCE LIMIT	SOOT/OPACITY	FREE WATER	FILTER FIBERS	CALIBRATION
Particle Counter	1.5 min (120mL)	0.5 min	<90x10³ p/mL	Skews Count	Skews Count	Skews Count	To Selected Standard (6 Months)
LaserNet Fines	2.3 min (.65mL)	1.5 min	>1x10⁶ p/mL	Auto Baselines	IDs Separate	IDs Separate	Intrinsic (Not Required)

Figure 3: LNF Compared to Laser Style Particle Counters

	PREP TIME	ANAYLSIS TIME	DEBRIS ID	FERROUS/NONFERROUS ID	FREE WATER	OPERATOR SKILL LEVEL	RESULTS
Analytical Ferrography	20 min	5-15 min	Morphology & Surface Features	Color/Hotplate Changes	Not Detectable	High (Analyst)	Subjectice Qualitative
LaserNet Fines	2.5 min	2.3 min	Morphology	None	IDs Separate	Same as Particle Counter	Quantitative (Wear Particle Counts)

Figure 4: LNF Compared to Analytical Ferrography

3.1. Using Ferrography as a Follow-up Analysis Technique

LNF analyzes the outline shapes of particles, or, their "silhouettes." Because the optical system within LNF uses transmitted light (back lighting), it is not possible for LNF to distinguish particle color, texture or surface attributes. These are extremely important attributes to consider when making an important root cause diagnosis. Therefore, the results you obtain for each wear category are only typical of that type of particle when it is viewed as a silhouette.

We recommend that if the size or quantity of particles in one of the abnormal wear particle categories (such as severe, fatigue or cutting) increases over a period of time, perform a microscopic examination to validate the particle classifications made by LNF. Ferrography (traditional Ferrography or Rotary Particle Deposition) or membrane filtration (filtergram) are possible follow-up techniques. Other types of non-machine wear related particles such as molybdenum disulfide; carbon flakes and seal material will be classified in one of the severe, fatigue or cutting wear categories depending upon their shape. This is because these particles block light and present a solid silhouette that the shape-recognition software categorizes as one of the solid particle types, that is, as sliding, fatigue or cutting.

4. Case Studies

The following two case studies further demonstrate the capabilities of LNF:

4.1. Case #1: Engine Test Cell

In this example, a used oil sample is retrieved from an engine during its break-in period and shows the synergy between LNF and other techniques such as spectrometric wear metal analysis and analytical ferrography. LNF results clearly depict the typical and expected high-levels of large wear particles during break-in.

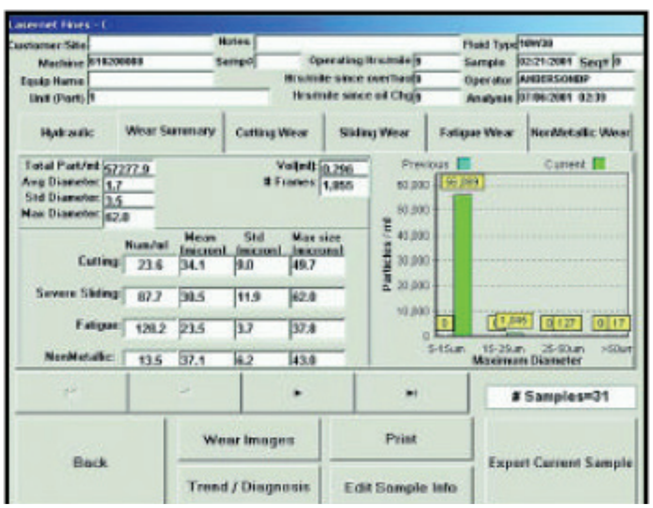

Figure 5: Wear Summary Screen

The bar graph of the wear summary screen in Figure 5 shows the large number of particles less than 15 μm in size. The number of particles greater than 20 μm is shown in the cutting, severe sliding, fatigue and nonmetallic wear categories.

An LNF image map of particle silhouettes for this sample is shown in Figure 6. The majority of large particles are identified by LNF and quantified in the wear summary as severe sliding and fatigue particles. This fact is confirmed by conventional analytical ferrography shown in Figure 7. Spectrometric oil analysis of this sample also shows a high level of wear metals including aluminum, copper and silicon.

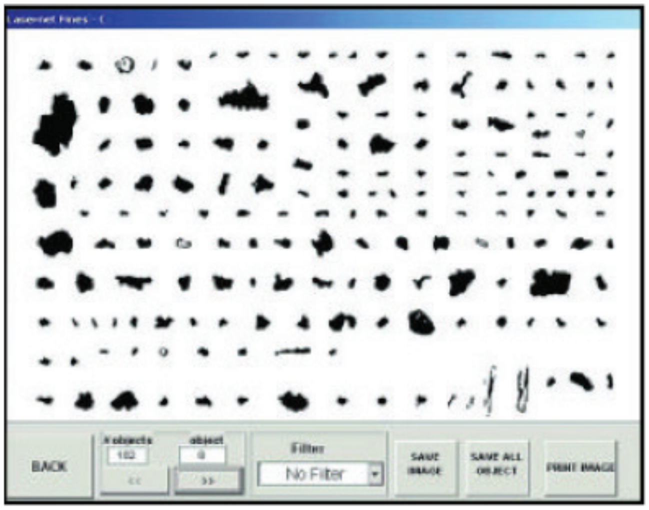

Figure 6: Image Map for Engine Test Cell Sample

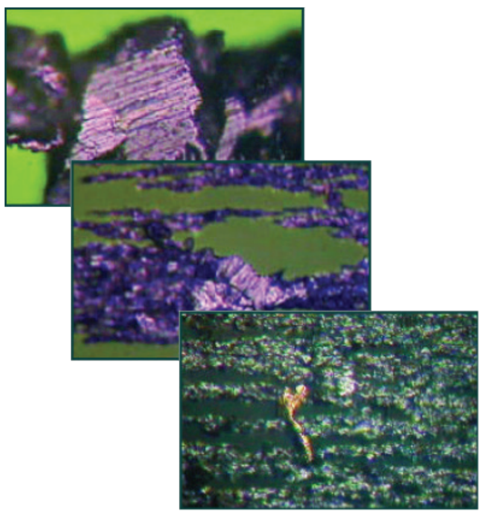

Figure 7: Ferrograms Showing Severe Sliding Wear and Copper Particle during Break-in

In this case, LNF clearly confirmed that the particles were formed during the engine break-in process, and are therefore considered normal wear. The close agreement between spectrometric, ferrographic and LNF data illustrates that the LNF instrument can identify an active machine wear mode or mechanism without the expense or subjectivity of a complete ferrographic analysis. However, if identification of the root cause of the problem is required or further corroboration is needed, we recommend a complete Ferrography analysis.

4.2. Case #2: Gearbox Accelerated Failure Test

Accelerated gearbox failure tests were conducted at Pennsylvania State University on their Mechanical Diagnostic Test Bed (MDTB) Facility under the ONR CBM program. These tests were conducted on single-reduction 10 hp gearboxes. The gearboxes were run-in for approximately four days at maximum normal load provided by an electric generator on the output shaft. After that, a 3X over torque was applied and the system then ran to failure. The system was stopped approximately every two hours for bore site inspection and oil sampling.

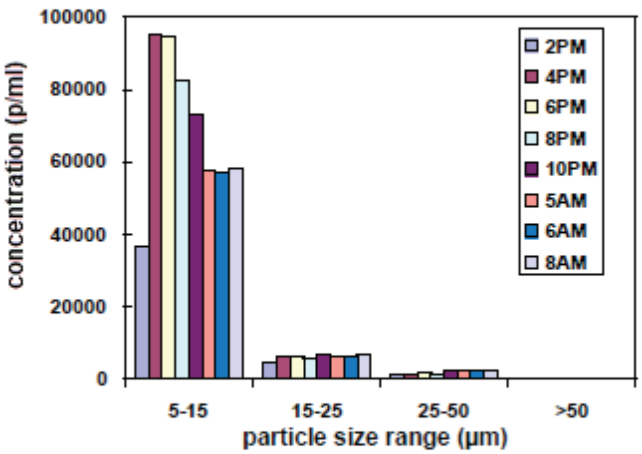

Figure 8: Gearbox Total Particle - Concentration Distributions

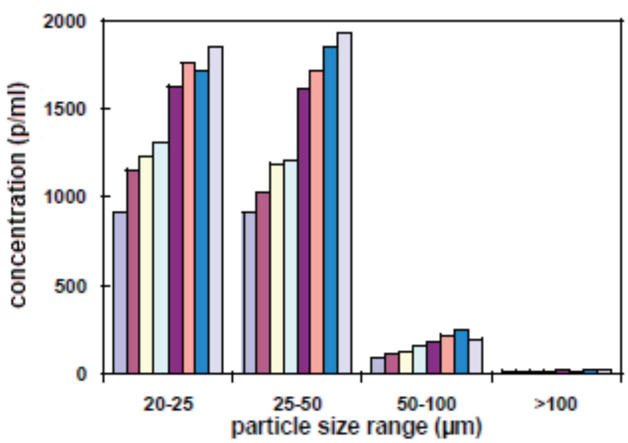

Figure 9: Gearbox Fatigue - Particle Concentration Distributions

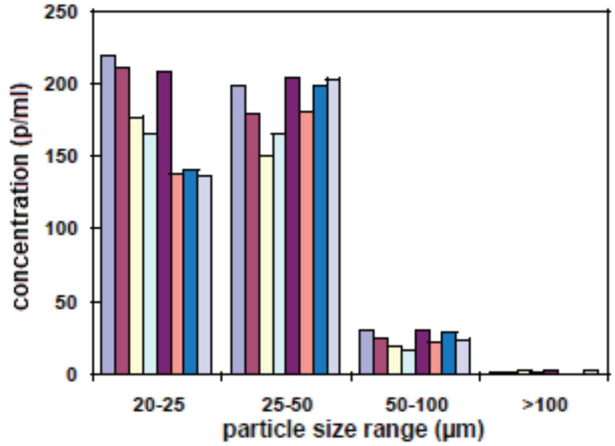

Figure 10: Gearbox Severe Sliding Wear - Particle Concentration Dilutions

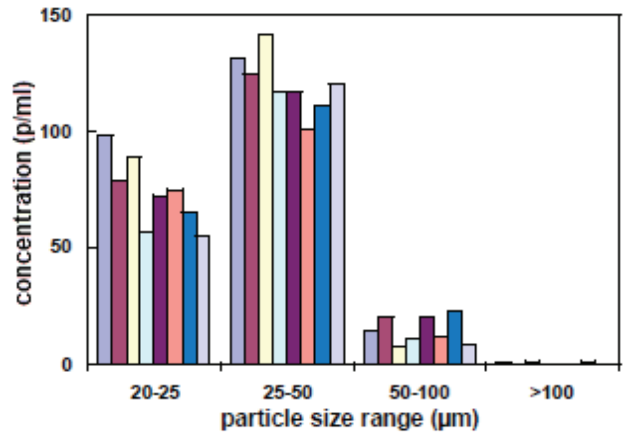

Figure 11: Gearbox Severe Cutting Wear - Particle Concentration Dilutions

Figure 8, histograms of the total particle concentrations are shown for different particle size ranges. Corresponding bars in the four size ranges are from the same sample. Oil samples were drawn at successive times during the test as indicated in the figures. A similar set of data for the particles classed as fatigue, severe sliding and cutting wear are shown in Figures 9, 10, and 11, respectively. All particle concentrations are corrected for fluid dilution because the gearbox lubrication level was topped off with clean oil to replace each extracted sample.

The first sample was taken at the end of the run-in period, with successive samples taken during over torque operation. The sample location was changed between the 2 p.m. and 4 p.m. samples, accounting for the change in total particles counted at those two sample times. Near the end of the test, several teeth on the output gear broke before the 5 a.m. sample.

In Figure 8, the total particle concentration in the 5-15µm size range shows a general decrease during the run, which was due to gradual removal of debris generated during the run-in period as samples were drawn and replaced with clean fluid. In Figure 9, however, an increasing concentration of fatigue particles are seen in several of the size ranges after the 3X over torque was applied. This behavior is apparent well in advance of the ultimate failure and is probably related to the excess wear conditions that lead to failure. Similar increases in the concentration of severe sliding and cutting wear particles were not seen in any of the size ranges (Figures 10 and 11). An increase of fatigue particles is expected in an over torque situation where excessive force is concentrated along the gear pitch line where rolling action occurs.

5. Conclusion

LNF is a unique analytical instrument and method that combines automatic particle shape classification and particle counting, two essential functions of used oil particle analysis.

As the case studies illustrate, by combining these two features, early signs of potential problems can be detected through increases in overall particle concentrations, and at the same time, the possible root cause of the problem can be diagnosed from shape classifications. Similar to complete analytical Ferrography, (without reflected light capability) LNF offers a unique insight into active machine wear, without the qualitative subjectivity and potential cost of comprehensive ferrographic analysis. It provides the ideal screening tool for analytical Ferrography, allowing sample data to be trended on a sampleto- sample basis.

The LaserNet Fines® Q200 instrument provides a dynamic solution to your detailed oil analysis needs while providing substantial cost-benefits compared to Optical Particle Counters and traditional ferrography techniques.

References

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[4] Mark Smith, Analysts, Inc., "Oil Analysis vs. Microscopic Debris Analysis – When and Why to Choose," Pages 1-9

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