

NEW RECOGNITION TECHNOLOGY FOR FLUID SYSTEMS CONTAMINATION

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Summary: Monitoring of technical condition of machines (e.g. engines) based on used oil analysis is an urgent practice to optimize control and maintenance. Both perfect wear products knowledge and used oil contamination is of crucial importance in order to make inspection, corrections or maintenance. The LaserNet Fines (LNF) technology [1] combines the technique of standard oil analysis, i.e., identification of number of wear and debris particles, automatic wear particle shape classification and trending tool to assist users in the field of ferrography. The LNF unit is a bench-top automated oil debris analysis unit which is a particle counter and shape classifier identifying sizes and trends wear particles and debris in all types of lubricants and hydraulic fluids.

1. Introduction

The LaserNet Fines is a bench-top instrument that analyzes hydraulic and lubricating oil samples from varies types of equipment and machinery that are a part of condition monitoring program. The monitoring is based primarily on the morphological analysis of the abnormal wear particles that are created from the internal components of the machine. As a secondary application, the LNF is also an excellent particle counter. The operator is presented with an assessment of particles found in the fluid sample and history of previous results for the same equipment. The LNF consists of two maid components, see Figure 1, a bench-top instrument in which the sample is processed, and a PC to operate the instrument and manage the analytical data. Guiding principle of particle laser analyzer can be seen in Figure 2.

In the LaserNet Fines, oil samples are processed individually, one after the other. In the default processing time, a sample run takes approximately 3 minutes after shaking and degassing; 1 minute to draw the sample into the flow cell and 2 minutes for the actual analysis. For most samples, the new sample will adequately flush the old sample from the flow cell during the initialization period. Highly viscous or highly contaminated samples may require a flash to eliminate cross-contamination before another sample is run through the instrument. The different stages of the wear cycle depicted by both Ferrographic analysis and the LNF wear trending screen can be seen in Figure 3.

The new equipment LaserNet Fines (LNF) utilized to run the samples for the purpose of this article is a bench-top automated oil debris analysis unit which is a particle counter and shape classifier that identifies, sizes and trends wear debris in all types of lubricants and hydraulic fluids. The instrument does not require any special preparation prior to analysis, nor does it

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require any special type of gases or fluids. Its main components are: Collimated Laser Diode, Progressive Scan Camera, Flow Cell, Computer with Frame Grabber, Imaging Optics and Operating and Data Analysis Software [1].



Figure 1: LaserNet Fines Particle counter and Shape Classifier



Figure 2: Guiding principle of particles laser analyzer LNF

Wear in Steady Wear (Normal Wear) Wear Out Abnormal Wear



Figure 3: The different stages of the wear cycle depicted by both Ferrographic analysis and the LNF wear trending screen

The test dust size distribution was measured using a sieve and optical microscope resulting in a size distribution based on maximum diameter. There is a significant difference between the two distributions and this can be shown; an automatic counter calibrates with Fine Test Dust (FTD) measures an ISO [11] as measured with a scanning electron microscope, see Figure 4. The equivalent circular diameter used by NIST regulation [11] for the same particle distribution is smaller than the maximum diameter used in the FTD, see Figure 5. A particle counter is calibrated using the new ISO regulation; the size of any solid particulate sensed will be over estimated because it will be blocking more light than a particle of the some diameter with transparent areas which it was calibrated with, see Figure 6.



Figure 4: Significant difference between the two distributions when an automatic particle counter is calibrated with two measures



Figure 5: Equivalent circular diameter used for particle distribution



Figure 6: Scanning and calculation the equivalent circular diameter

2. Example of analysis

Tabla 1

Complete case histories of samples were analyzed using the LNF. The samples were also run on an optical emission Spectrometer to check for any abnormal wear metal concentrations. From the LNF results specific samples from the set were chosen for a more in depth morphological analysis using the Ferrogram maker and the optical microscope [2]. The main purpose of the test program was to evaluate the shape recognition features of the LNF and compare them to the more conventional morphological analysis technique using the Ferrogram Maker and the optical microscope. The LNF can handle various lubricants with viscosities up to $350.10^{-3} \text{ m}^2 \text{s}^{-1}$ and with varying fluid darkness [3]. The oils which were analyzed, see Table 1, and presented in this article are from different applications and vary from hydraulic fluid to diesel crankcase oils. The different types of application attributed to each oil are listed below together with some comments which were observed from other used oil analysis techniques.

Sample Nr	Application	Comments
1	Oil from an engine compressor	High Cu content
2	Oil from a hydraulic system	Fe and Cu increased
3	Oil from a car automatic transmission	Cu, Pb and Ag
4	Oil from a manual transmission	Failed shortly after
5	Oil from the Tatra 930 engine	No abnormal findings

Visual inspection of the samples showed that they were not heavily sooted and therefore did not require a dilution with base oil the samples were first shaken using an automatic shaker. Before the analysis was undertaken the samples were shaken for a further 30 seconds and then placed in an external ultrasonic bath to remove air bubbles. Each sample took approximately 2mins 30 seconds to be initialized and analyzed on the LNF bench top unit. All the size resolutions and shape classifications are presented in a spreadsheet format in this article. This format is identical to the results which would be output from the LNF to a LIMS or other data information management station. This article also contains some individual screen shots of some of the different result screens. The Wear Summary screen shows particle concentrations based on maximum diameter compared to the Hydraulic screen which can present the results in either NAS 1638 or a NAVAIR [11] code format based on circular diameter [4]. The ISO particle counting codes and free water concentration are also presented in each of these screens. The graphical results page also shows a composite image map together with some enlarged particle type examples. The magnified particles are viewed by clicking on any particle within the samples composite image map [5]. Once the particle of interest has been selected it is shown in another window with its size statistics. It can then be zoomed in or out using the zoom buttons.

Sample Nr 1

Wear Summary (Max diameter)

Hull Number	2132		N	lotes					Fluid Type	NOT KNOWN
Equip RIN 2132 Equip Name Valve Loc 1					Operatin Hrs/mile Hrs/mil	g Time since o e since		Sample 05/04/200 Seq # 1 Operator SEBOK Analysis 05/04/2001 14:23		
Hydrau	ılic	Wear Su	mmary	Cutting	Wear	Slidir	ng Wear	Fati	gue Wear	Oxide
Total Parl Avg Diamo Std Diamo Max Diamo	t/ml: 134 eter: 9.9 eter: 4.5 eter: 14(1 <u>7826</u> 		#	Vol(ml): Frames:).65 3,666	Prev 1,280, 1,120, = 960	ious (1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	71,106	Current
	Cutting:	Num/ml 1609.8	Mean <u>(micron</u>) 24.3	Std fmicron 3.8	Max s 1 <u>(micro</u> 47.4	ize nsl	articles / n 800, 800, 800, 800, 800, 800, 800, 800,	000 000 000		
Severe	Sliding: Fatigue:	9541.6 21319.4	24.6 21.5	3.8	68.5 63.6		320, 160,	000	2016	9,755
	Oxide:	7945.7	23.9	4.3	146.9	_		5-150	m 15-25 Maximu	5um 25-50um >50u ImDiameter
H			4		\triangleright		M			# Samples=2
E	Back		We	ear Imag	es		Print		Exp	ort Current Sample
			Trend	1 / Diag	nosis	Edi	t Sample	Info		

Composite Image Map



Hydraulic Screen



Zoomed Oxide Particle



The sample showed a considerably high count of fine debris below $15\mu m$. Abnormal wear (>15microns) was also present in high quantities in each of the severe wear classes. A large number of oxidative particles above 50 microns were also seen on this sample (see zoomed oxide particle) which may well have been caused by the high water concentration (42.7ppm-see above) also observed in this test [6].

Sample Nr 2

Wear Summary (Max diameter)

Hull Number 2142			lotes				Flui	d Type	NOT KNOWN	
Equip RIN 2142			Operating Time Hrs/mile					Sample 05/04/200 Seq # 0		
Equip Name			E F	lrs/mile	since o	verhaul	Ope	rator	SEBOK	
/alve Loc 1	~			Hrs/mil	e since	oil Chg	An	alysis 🛛	05/04/2001 13:03	
Hydraulic	Wear S	ummary	Cutting V	Near	Slidir	ng Wear	Fatigue	Wear	Oxide	
Total Part/ml: 3. Avg Diameter: 9 Std Diameter: 6	147.0 8 2		۱ ۴ F	ol(ml): rames:).65 3,668	Previo 3,000	us 2,952		Current	
Max Diameter: 5	9.0					E 2,500				
	Num/ml	Mean fmicron	Std 1 (micron)	Max s Ímicro	ns)	s 2,000				
Cuttin	F 9.2	23.9	2.6	27.8		₽ 1,500				
Severe Slidin	24.6	27.2	6.4	45.4		₽ 1,000 500		432]	
Fatigu	61.5	26.7	7.0	49.3			0	0	0 62 0 2	
Oxid	27.7	30.0	9.9	59.0	_	5-	15um 1 M	5-25um aximur	25-50um >50um n Diameter	
M		\triangleleft		►		►I		#	Samples=1	
Back	_	We	ear Image d / Diagn	es	Edi	Print t Sample I	nfo	Ехро	rt Current Sample	

Composite Image Map



<u>Hydraulic</u>

lull Number	2142			Notes			Fluid Type	NOT KNOWN
Equip RIN Guip Name				Operati Hrs/mile	Sample Operator	ample 05/04/200 Seq # 0 berator SEBOK		
alve Loc	1				Hrs/m	ile since oil Chg 🗍	Analysis	05/04/2001 13:03
Hydrau	ılic	Wear	Summary	Cuttin	ıg Wear	Sliding Wear	Fatigue Wear	Oxide
WATER	CURR	ENT	PREVIOUS		<u>r</u>	Display C NAS 1638	• NAVAIR	01-1A-17
ISO 4406	19 /	15		I	=	Previous	Curr	rent 🗖
	1	IAVAIR	01-1A-17		= 2 ²			
NAVAIR		6			les /I	,500	 a	
5-10 um	1879.6	6			artic	,000		
10-25 um	826.0	6			۵	500	015	
50-100um	15.4	- 5						
>100 um	0.0	0				5-10um 10-25 Cire	um 25-50um 5 cular Diameter	0-100um >100um
R			<		►	FI		# Samples=1
			w	ear Ima	iges	Print		
	Back Tre						Export Current	

Zoomed Fatigue Particle



This sample showed a relatively high (abnormal) cleanliness code for a hydraulic fluid. The abnormal wear particle counts were found to be highest in the fatigue category (see zoomed fatigue particle) which may account for the high copper and iron levels established in previous tests.

Sample Nr 3

Wear Summary (Max Diameter)

Hull Number 2167		N	otes				FI	uid Type	DEXTRON 3	
Equip RIN 2167			0	peratin	g Time	Hrs/mile 0	S	ample	05/04/200 Seq # 1	
Equip Name			н	rs/mile	since o	verhaul	O	perator	SEBOK	
/alve Loc 1	-			Hrs/mil	e since	oil Chg	A	nalysis	05/04/2001 13:22	
Hydraulic	Wear Su	immary	Cutting V	Vear	Slidir	ng Wear	Fatigu	ie Wear	Oxide	
Total Part/ml: 539 Avg Diameter: 8.3 Std Diameter: 4.8 Max Diameter: 57.	6	1	V # Fi	ol(ml): rames:).65 3,668	Previ 5,00[4	ous]	Current	
	Num/ml	Mean (micron)	Std (micron)	Max s (micro	ize ns)	E 4,000				
Cutting:	9.2	30.7	12.1	54.6						
Severe Sliding:	21.5	27.9	9.1	56.9	_	a 2,000				
Fatigue:	47.7	25.3	6.1	45.8	_	1,000		27 295	37 38 5 5	
Oxide:	16.0	35.0	44.4	57.6	-		5-15um	15-25un	n 25-50um >50um	
1	1 10.5	55.0	1	137.0		ļ.		малтти	in Diameter	
H		-				D1			# Samples=2	
Back		We	ar Image	s		Print		Even	ut Currout Samula	
Dack	Back		l / Diagno	osis	Edi	t Sample	Info	Export Current Sample		

Hydraulic Screen

full Number 2167				Notes			Fluid TypeDl	EXTRON 3		
Equip RIN 2167 quip Name					Operatii Hrs/mile	g Time Hrs/mile 0 since overhaul	Sample 05 Operator SI	Sample 05/04/200 Seq # 1 Operator SEBOK		
lve Loc	1				Hrs/mi	le since oil Chg	Analysis 05	5/04/2001 13:22		
Hydrau	ılic	Wear	Summary	Cutting	g Wear	Sliding Wear	Fatigue Wear	Oxide		
WATER	CURR	ENT	PREVIOUS		L	Display C NAS 1638	• NAVAIR 01	-1A-17		
ISO 4406	19 /	13	19 / 13	IT IT	- 4	Previous	Currei	nt 📕		
	ı	AVAIR	01-1A-17		= 3					
NAVAIR		6	6		es/I	500				
5-10 um	3359.3	6	6		artic	500				
10-25 um	569.1	6	6		<u>a</u> 1	500	569			
25-50 um	15.4	5	5			0				
50-100um	0.0	0	0			5-10um 10-2	5um 25-50um 50-	100um >100um		
-ite un	0.0] 0	0			Ci	rcular Diameter			
H			4			PI	#	Samples=2		
			1.1					oumpres 2		
			w	ear Ima	ges	Print		_		
Back Tr						Export	Export Current Samp			





Zoomed Sliding particle



The earlier findings of Copper and lead may account for the abnormal wear counts which were prevalent in the Fatigue and Sliding categories.

Sample Nr 4

Wear Summary (Max Diameter)

Hull Number 2171 Equip RIN 2171 Equip Name /alve Loc 1				lotes Operating Time Hrs/mile Hrs/mile since overhaul Hrs/mile since oil Chg					Fluid TypeNOT KNOWN Sample 05/04/200 Seq # Operator SEBOK Analysis 05/04/2001 13:46		
Hydraul	lic	Wear Su	immary	Cutting	Wear	Slidir	ng Wear	Fatig	ue Wear	Oxide	
Total Part Avg Diame Std Diame Max Diame	/ml: <u>567</u> ter: <u>7.7</u> ter: <u>4.2</u> ter: <u>64.</u>	65.8		# 1	Vol(ml): Frames:).648 3,658	Prev 60,000 50,000	ious 52 53,8	99) 	Current	
C	, Cutting:	Num/ml 40.1	Mean <u>(micron)</u> 31.9	Std fmicron 13.3	Max s 1) <u>fmicro</u> 61.1	ize nsl	40,000)-)-			
Severe S	Sliding:	115.7	28.9	9.2	63.0		10,000)-	2,6 2,568		
F	atigue:	438.0	24.2	5.3	57.6	_	c	5-15um	15-25um Maximum	25-50um >50ur	
H			4	13.0		1	M		#	Samples=2	
			We	ar Imag	es		Print				
В	Back		Trend	l / Diagi	nosis	Edi	t Sample	Info	Expor	t Current Sample	

Hydraulic Screen



Composite Image Map



Zoomed Cutting wear particle

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ſ	
Width(um) 56.1 Height(um) 26.8 Class Max Diameter(um) 56.8 Circular Diameter(um) 25.7	Cutting

The particle counts showed a high ISO code together with high counts in all the severe wear categories (see composite image map). The Fatigue category showed the highest count but what is also of concern is the relatively high cutting wear counts which show classical cutting wear particle morphology (see zoomed cutting wear particle) [7]. The quantity and severity of the wear particles would indicate that the equipment was undergoing a severe wear mode. This was seen to be the case when the transmission failed soon after.

Sample Nr 5

Wear Summary (Max Diameter)

Hull Number 2174		N	lotes				Flu	iid TypeN	DT KNOWN
Equip RIN 2174			18	Operatir	ng Time	Sa	Sample 05/04/200 Seq # 1		
Equip Name				Hrs/mile	since o	verhaul	Op	erator SE	BOK
/alve Loc 1	-			Hrs/mi	le since	oil Chg	A	nalysis 05	5/04/2001 15:18
Hydraulic	Wear Su	immary	Cutting	Wear	Slidi	ng Wear	Fatigu	e Wear	Oxide
Total Part/ml: 67. Avg Diameter: 8.0	16.9		#1	Vol(ml): Frames:	0.65 3,666	Previ 7,00	ious 🔽		Current
Max Diameter: 78.	4					6,000- E 5,000-			
	Num/ml	Mean (micron)	Std (micron	Max s	ize Insl	S 4,000			
Cutting:	3.1	23.6	1.5	25.1		3,000			
Severe Sliding:	7.7	33.5	7.1	45.6		[₽] 2,000 -			
Fatigue:	83.1	24.3	4.8	45.8		1,000		36 3/9	83 52 12 3
Oxide:	35.4	32.2	14.9	78.4	_		5-15um I	15-25um Maximum	25-50um >50um Diameter
H	[•			1	M		#	Samples=2
	1			1				1	
Back		We	ar Imag	es		Print		Export	Current Sample
		Trend	l / Diagr	nosis	Edi	it Sample	Info		

Hydraulic Screen



Zoomed Sliding Wear Particle



The ISO particle counts would not suggest anything too abnormal. However, the counts in the Fatigue category >20 μ m are high and would indicate a possible rolling contact wear mechanism [8]. The previous analysis tests found no abnormal findings within the engine of this piece of equipment. The LNF found some evidence of an abnormal wear mode in the form of fatigue particles which should warrant some concern and possibly further ferrographic analysis. In Figures 7 – 12 there can be seen results of ferrographic analysis of some choice samples we analyzed as our example (Table 1) [9].

Composite Image Map



Figure 7: Severe sliding wear particle, approximately 75 µm



Figure 8: Two large particle 30 µm, generated during break-in



Figure 9: Chunky, 70 µm, during break-in wear



Figure 10: Fine rubbing wears debris, $< 20 \ \mu m$



Figure 11: Fine rubbing wears debris, $< 20 \ \mu m$



Figure 12: Severe rubbing debris, $40 \ \mu m$

3. Conclusion

- 1. The sample results were found to be repeatable by running each sample for every application twice, except for sample 2 for which there was insufficient volume to run twice
- 2. The LNF was able to account for the high oxide particle counts in sample 2 because of the elevated water content it also detected and quantified.
- 3. The elements of copper and lead, which were found in earlier tests, are commonly found on their own or as alloying elements in journal (plain) bearings. The high fatigue counts may be bearing material.
- 4. The LNF was able to detect a severe wear mode by identifying and quantifying the morphology of severe wear particle types. (sample 4) This was further backed up when the transmission failed shortly after being filled with this oil.
- 5. The LNF is still able to detect abnormal wear which is undetectable by other instruments (sample 5). Analysis of a ferrogram would be able to back this analysis up if the LNF was used as a form of screening device.

The LNF-C results were found to be extremely consistent in terms of both the quantitative and qualitative aspects of more traditional techniques, namely Ferrography and Spectrometric analysis. The limitations of atomic emission spectroscopy have always been its inability to accurately quantify wear metal concentrations above 10 microns. However, it seems that in this particular failure mode enough small sub 10 micron aluminum debris was able to be detected [10]. The LNF's shape recognition feature showed a substantial increase in both fatigue and severe sliding debris during the final hours and although it is impossible to ascertain the nature and source of the debris by this method it certainly would warrant a detailed Ferrography analysis by an expert analyst. The Ferrography analysis which was undertaken clearly shows how well both the overall particle counts and the more detailed particle types compare with the LNF results. The aluminum particles can easily be identified by ferrography because they are non ferrous which means that the larger particles will be randomly deposited down the length of the ferrogram and not necessarily with their longest edge leading across the width of the ferrogram, as is the case with ferrous metals. The particles also appear very bright in comparison with the other debris as can be seen by some of the particle images presented in this report. It is not feasible to make Ferrograms and analyze each and every sample because Ferrography is both time consuming and expensive. However, this article has shown how both the LNF and Atomic Emission Spectroscopy can be used in conjunction with each other and be used as screening tools before a Ferrography analysis needs to be undertaken. The LNF can complement Ferrography by taking away the subjectivity and automating it to a point when a more definite answer needs to be obtained.

4. Acknowledgments

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