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PARTICLE COUNTERS FOR OIL ANALYSIS: DESIGN AND SPECIFICATIONS

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Synopsis

This article presents an introduction to the design and use of particle counters for in-service oil analysis. It compares the key operating parameters of light blockage particle counters with the LaserNet Fines® LNF Q210 direct imaging particle counter.

The LNF Q200 was initially developed to determine wear classification. With the introduction of a full range of LNF products (Q210 Particle Counter, Q220 Particle Counter and Wear Classifier and Q230 Particle Counter, Wear Classifier and Ferrous Monitor), it is appropriate to review the key attributes of the LNF Q210 as a particle counter compared to traditional light blockage instruments.

Introduction

When implementing machine condition monitoring for machinery lubricating oils, typically the first strategy you implement is contamination control. Particle counting is the method used to monitor the solid contamination of new and in-service fluids. Solid contamination sources include solid oxides from surface oxidation inside the machinery, sand and dirt from the environment, worn mechanical seals, filter blow-by and deterioration, and machinery burrs.

The most aggressive form of abnormal machinery wear is abrasion caused by hard particles embedding in a softer metal when it is gouged by a moving surface. Studies have shown that up to 50% of equipment downtime is due to abnormal wear.

Particle counters measure all particulate regardless of the composition or shape of the particle. The output from a particle counter typically includes particle count, size distribution, and an ISO code. Other reporting codes are also in use but ISO 4406 is the most common. An ISO code is convenient shorthand that summarizes oil cleanliness. Each increase in an ISO code represents a doubling of the number of particles in that size range. ISO codes for particles >4, >6, and >14 µm are reported per the ISO 4406 standard.

ISO 4406 CHART

RANGE CODE	PARTICLES PER MILLIMETER	
	MORE THAN	UP TO/ INCLUDING
24	80000	160000
23	40000	80000
22	20000	40000
21	10000	20000
20	5000	10000
19	2500	5000
18	1300	2500

PARTICLE SIZE	PARTICLES PER ML*	ISO 4406 CODE RANGE	ISO CODE
4µ(c)	151773	80000-160000	24
6µ(c)	38363	20000-40000	22
10µ(c)	8229		
14µ(c)	3339	2500-5000	19
21µ(c)	1048		
38µ(c)	112		

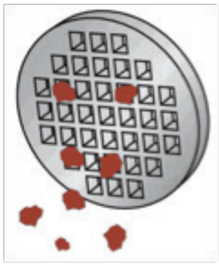
Particle count, size, distribution and ISO code output from particle counter.

Types of Particle Counters

Several types of particle counters that address machinery oil analysis are described below:

Pore blockage

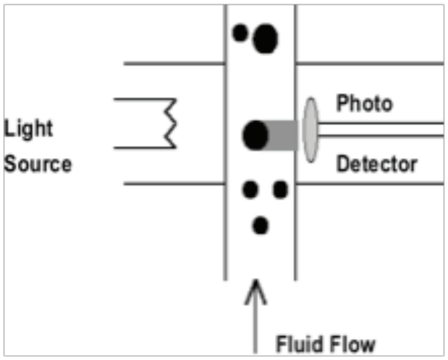
Pore blockage particle counters are used as on-site particle counters for in-service machinery oils. They employ a fine mesh whereby particulate accumulates on the mesh. These particle counters are based upon either a constant flow or constant pressure design. Constant flow instruments measure the pressure drop across the mesh while holding flow constant. The constant pressure designs measure the change in flow rate while holding the pressure constant. In both cases, the particle count distribution is estimated by extrapolation. A typical pore blockage mesh design yields one or two ISO codes. Pore blockage particle counters are rarely used by commercial laboratories due to the limited data generated.



Light blockage particle counters

Laser light blocking particle counters are the traditional instruments used for in-service oil analysis. The working principle of traditional light blockage particle counters is depicted below.

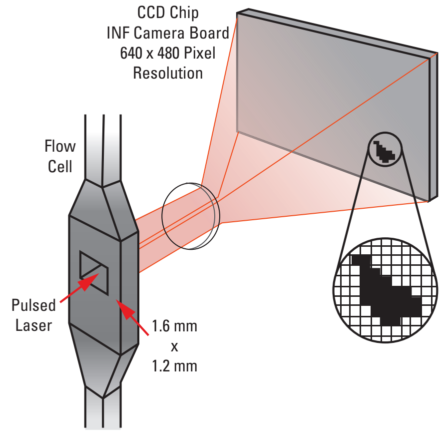
A light source, typically a laser, passes through a sample. The light is partially blocked by particles so less light reaches the photodetector array, resulting in a change in voltage proportional to the area of the particles. The photo detector technology is the same principle used in garage door openers.



Traditional light blockage particle counters have several inherent design limitations. The photo detector results contain measurement errors caused by the presence of water and air bubbles within the oil sample. Properly preparing your sample by using ultrasonic agitation helps reduce the impact of air bubbles on particle count. For water containing samples (an oil sample that is 'milky' contains water), it is common to need 'water stripping' solvents to get a more accurate count. The presence of water results in a significant error in the reported particle count.

LaserNet Fines direct imaging particle counter

The design of the LaserNet Fines (LNF) particle counter incorporates a solid-state laser configured with a CCD array to create a direct imaging particle counter as depicted in the illustration below.



The laser illuminates the sample, and an optical lens magnifies the laser light. A CCD video camera captures the images of the sample and stores them in memory. These images are analyzed for size and shape. An equivalent circular diameter or ECD is calculated for each image and particle count and size distribution is reported along with ISO codes. The LNF provides other output formats but ISO 4406 is the most common.

The capability of the LaserNet Fines to capture the actual wear particle silhouette allows for an 'Automated Ferrography' capability for wear particle classification. All particles larger than 20 μ are classified by a neural network in the categories of cutting, fatigue, severe sliding, non-metallic, free water and fibers. Identifying the type of wear particle and providing particle count, size distribution and severity of each of the abnormal wear mechanisms complements information provided by other instrumentation technologies such as ferrous monitoring and analytical ferrography. This capability is implemented on the Spectro LNF Q220 and Q230 instruments and is described in more detail on spectrosci.com and in other documentation.

The LNF can distinguish between solid particles, water droplets and air bubbles in oil for all particles greater than 20 µ. Water and air bubble counts are subtracted from the measured particle count to yield a true net particle count.

LNF and Light blockage particle counter comparison

Key parameters and specifications for particle counters used for in-service oil analysis are described below and a summary of the LNF compared to light blockage particle counters is provided in Table 1.

Calibration

The LNF calibration is a one-time, factory calibration performed on an optical bench. No other routine calibration is required, performance is validated by simply running the standard sample test using PartiStan™ calibration fluid.

Calibration of light blockage particle counters is required annually due to electrical drift, and it is rarely possible without returning the instrument to the manufacturer. Laser light blockage particle counters are calibrated in accordance with ISO 11171. The LNF is traceable to NIST without the need for ISO 11171.

Saturation level and coincidence error

Coincidence loss is when two or more particles pass through the detection area and are counted as one particle. It occurs when the concentration of particles is too high for the detector. It causes bias when reporting low particle count results and also inaccurate sizing of particles.

Saturation limit is the upper range of detection, measured in particle concentration (particles/ml). It is typically defined as the value at which an instrument has a 10% coincidence error.

The saturation limit of the LNF is the highest available with a specification of 5 million particles /ml with a coincidence error of 2%.

There are several reasons why the LNF has such high saturation levels and low coincidence errors compared to a light blockage instrument. The LNF uses a two dimensional 640 x 480 array in contrast to a one dimensional point source photodetector. Additionally, many particles are viewed simultaneously within an area of 1600 x 1200 microns inside the LNF flow cell. It tracks the trajectory of individual particles and can monitor any subsequent separation of the image into two smaller ones. A photodiode cannot do that. It is possible only with a direct imaging instrument.

In comparison, conventional laser light blockage particle counters are typically limited to a saturation level of 80 - 200,000 particles/ml with coincidence errors of 8 to 10%.

FACTORS	OPTICAL PARTICLE COUNTERS	LNF Q200
Calibration	Annual Calibration, typically by Manufacturer.	No Calibration required. Validate as desired with PartiStan.
Dilution	Yes, for dark oil, dirty oil or high viscosity oil.	For high viscosity oil (>320 cSt) only.
Coincident error	Typical 8-10%	< 2%
Saturation level	10,000-300,000 parts/ml (typical)	5,000,000 parts/ml
Equivalent circular diameter	Estimate. Based on light transmission. Errors with semi-transparent particles and water bubbles.	Actual. Detects and classifies non-metallics, water and air bubbles > 20um.
Repeatability	Poor. Multiple tests needed, typical lab reports an average of three measurements.	Excellent. No multiple tests needed.
Automation	Yes, factory supplied turnkey.	Yes. Field expansion possible.

Table 1

Dilution

Diluting oil samples is sometimes required to process them using a particle counter due to high viscosity or high particulate, or both.

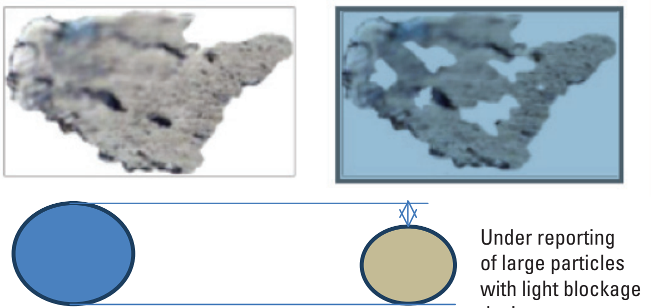
Laser-based particle counters, with an inherently low saturation limit, will frequently require dilution, especially for darker engine oils or samples with high particle counts. Without dilution, too many particles will saturate the sensor and higher counts will not be recorded.

When oils are diluted additional particle count errors are introduced; they increase linearly with the dilution factor. In addition, particles from the solvent are also introduced during the dilution process. It is a common recommendation to dilute samples at a 1:1 ratio. At these levels the oil acts as a solvent causing large particles to settle quickly. It is difficult to homogenize a sample and get repeatable results at these levels.

LNF's high saturation limit allows it to measure darker and dirtier oils without dilution. Dilution is only required for samples over 320 cSt. The higher range of the LNF allows testing of most machinery and engine oils without dilution, making results more accurate and repeatable compared to laser-based particle counters.

Non-metallic particle count

Another unique feature of LNF instruments is the ability to discern semi-translucent particles from solid particles. Consider two particles with identical areas and shape, one is partially translucent. Silica and silicates (in sand and dirt) are often semi-translucent and are the primary components of contamination. The LNF capability allows the monitoring of a non-metallic (contaminant) particle count in addition to the total particle count.



Semi-translucent particles and Equivalent Circular Diameter calculation

Equivalent circular diameter calculation

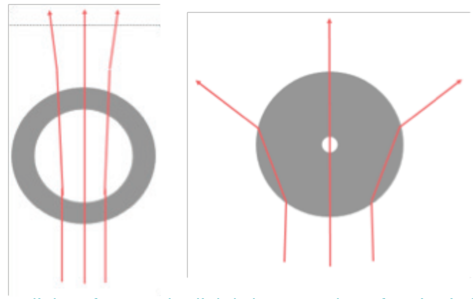
Particle counters report particle size in 'Equivalent Circular Diameter'. This is the diameter of a circle with the same area as the actual, irregular shaped particle detected. When you calibrate using a laser light blockage system, semi-translucent particles will pass light so that the full area of the silhouette is not measured on the photodetector, resulting in under reporting of large particles. The direct imaging LNF does not have this limitation as the neural network 'fills in' the missing areas for a precise sizing of the particle.

Water and air bubble correction

The LNF has the ability to make corrections to the indicated particle count, based on the presence of water and air bubbles. Water and air bubble counts are subtracted from the reported particle count and are readily identified due to the differences in refractive index between oil, water, and air.

Soft particles

Accurate particle counts require eliminating the contribution of 'soft particles' such as water, additives and by-products that are insoluble in oil. Like particulate, they scatter the laser light and will give a false count with a high bias.



At left, laser light refracts only slightly because the refractive index of the water is very close to that of the oil. At right, laser light refracts considerably because the refractive index between the oil and the air differs greatly.

The LNF measures and reports, as a separate category, particle count for all water droplets over 20u. Using this capability it is easy to determine if enough water is present to require a water-stripping solvent preparation technique (ASTM D7647).

Conventional light blockage systems have no direct means to evaluate the presence of water.

Free water measurement

LNF instruments measure and report the free water in a sample. This measurement uses the images of all water droplets larger than 20 μ in diameter and correlates to the Karl Fisher titration method.

Soot measurement

The LNF measures soot levels up to 2% by using automatic gain control of the laser to image through a sample. Soot percentages are derived from the transmission through the oil sample. The calibrated soot percentage can then be measured accurately down to 0.01% compared to TGA standards.

Summary

A comparison of the operational specifications and ease of use of the Laser Net Fines Q200 Series with light blockage particle counters illustrates how the LNF is the optimal particle counter for in-service oil analysis.

It delivers particle count codes for particles from 4-100 μ with multiple output codes. It also provides error corrections for water and air bubbles. Finally, it provides a non-metallic particle count for contaminant monitoring in addition to the total particle count.

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