WEARCHECK Technical Bulletin

Issue No 1

Particle Counting and Contamination Analysis in Fluid Power Systems

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In January 1992 Wearcheck introduced particle counting to its battery of tests.

Introduction to methods of contamination analysis

Typically, most oil analysis companies have relied on spectrometric and debris analysis for the detection of wear particles and contaminants in oil lubricated components. The ICP (inductively coupled plasma) spectrometer used by Wearcheck is limited to a maximum particle size of eight microns that it can detect, so other techniques must be employed to detect larger wear particles and contaminants. The ideal situation would be to filter all oil samples and examine any debris under a microscope; this is highly labour intensive in terms of sample preparation and visual analysis of the debris and only provides a qualitative description of the debris.

Wearcheck uses particle quantification as a screening test to detect the presence of wear particles greater than eight microns. In this test a bulk magnetic measurement of the oil is made and a particle quantification index is determined; depending on the level of this index and the type of component the oil has come from, a visual debris analysis will be made.

Particle quantification, however, also has its drawbacks. Because it is a magnetic measurement, it only detects the presence of ferrous particles in the oil and takes no account of other types of contaminants in the oil, eg. coal dust, coarse dirt, fibrous material, etc. In January 1992 Wearcheck introduced particle counting to its battery of tests. In this test, the total number of particles, irrespective of origin, are counted in a number of sizes, ranging from 5 to 400 microns. The results are expressed as the total number of particles per ml of oil in the various specified size ranges.

A brief history of fluid power

This test is of particular importance to clean oil systems, eg, hydraulics, transmissions, turbines, compressors and other fluid power systems. It has been shown that 70 - 85% of hydraulic component failures are due to particulate contamination with up to 90% of these failures due to abrasive wear.

The concept of fluid power systems dates back to the times of Archimedes and the invention of the screw pump. In the 15th century, Leonardo da Vinci advanced many ideas including that of the hydraulic press. In the 16th and 17th centuries both Galileo and Pascal were

Wearcheck uses a Hiac/Royco model 8000A automatic particle counter.

involved in the development of hydraulic power theory. Many consider Pascal to be the true father of hydraulic power systems. The industrial revolution saw the development of the hydraulic press by Joseph Bramah and the use of hydraulic power was demonstrated to the Duke of York in 1813 by uprooting a tree in Hyde Park. The hydraulic power industry was finally recognized in 1925 and since that time there has been concern over contamination and cleanliness of hydraulic fluid power systems. Actual particle counting techniques were developed in the late 1950's and early 1960's.

Particle counting techniques

In this test the oil is drawn through a membrane of known pore size and the number of particles in a variety of size ranges is counted by viewing the membrane under a microscope. Although this technique is still used today, it is tedious, time-consuming and unreproducible when compared to other techniques.

Other contaminant analysis techniques exist, such as Patch Tests, Gravimetric Analysis and determination of silting indices. All these tests, whilst providing total contamination levels, provide no information on the distribution of particle size.

Image analysers using video and computer systems give accurate particle count information. However, this method is time-consuming and very expensive. In the mid 1960's, automatic liquid particle counters were developed and this is now the preferred technique for particle counting in the 1990's as many advancements and refinements have been made with instrumentation in the last 30 years.

Automatic liquid particle counters operate on three general principles: electrical resistance, fluid flow decay and light blockage. As electrical resistance (coulter counters) devices depend on the medium under test to conduct electricity, these systems are rarely used in oil analysis. With fluid flow decay devices, such as the Diagnetics Instrument, the oil is passed through a screen of known mesh (usually ten microns) and the time taken to plug the screen is determined, the instrument then calculates the distribution in other size ranges by extrapolation. The disadvantage of using this technique is that it assumes a predetermined size distribution without actually measuring the number of particles in each size range. The most common types of automatic particle counters operate on a light blockage principle when oils are being analysed.

With this type of instrument, a known volume of oil (usually 5ml) is injected through a very small sampling cell. On one side of the cell is a beam of laser light and on the other side, a detector. As particles pass through the cell, they block the beam of light and thus cast a shadow on the detector. The drop in light intensity received by the detector is proportional to the size of the particle blocking the light beam. In this way, both the number and size of the particles can be measured.

Particle counting by light blockage

The instrument that Wearcheck uses is a Hiac/Royco model 8000A automatic particle counter and it operates on this light blockage principle.

The instrument is set up to measure particles in eight different size ranges. Those size ranges, in microns, are as follows: 5-10, 10-15, 15-20, 20-25, 25-50, 50-75, 75-100 and greater than 100. The results are expressed as the

Wearcheck calibrates its instrument with the mono-sized latex sphere method.

total number of counts (particles) per ml of oil. With the advent of automatic particle counters it was realised that some form of categorisation of particle counts was needed in order to determine if an oil was "clean" or "dirty".

During the 1960's a number of systems for the classification of oil cleanliness was developed, among them were the SAE 749D, NAS1638 and MIL1246A.

While these enjoyed some popularity in the 1960's they were all eventually discarded, the main problem being that all these early classification systems assumed a fixed particle/size distribution.

Finally, in July 1972 a system of cleanliness classification was proposed and eventually ratified by the International Standards Organisation in September 1974. The system is known as the ISO 4406 and is still in use today. This system reflects the philosophy of contamination control experts throughout the world and can be used to describe a theoretically infinite range of contamination levels in oil.

The ISO 4406 cleanliness rating is expressed as a two number code X/Y, where X represents the total number of particles per ml greater than five microns and Y represents the total number of particles per ml greater than 15 microns.

These two sizes were selected because it was felt that the smaller size would give an accurate assessment of the "silting" condition of the fluid, while the population of the particles greater than 15 microns would reflect the prevalence of "wear"catalysts.

The ISO Standard on pages 5 and 6 gives an explanation of the relationship between the X/Y code and the actual number of particles per ml in the chosen size ranges.

Calibration of particle counters

For any laboratory instrument to give meaningful and accurate results it must first be calibrated against a precisely known standard. Unfortunately, there are two methods for accurately calibrating the instrument and these two methods give different results. The first method involves using a very clean oil and dispersing an accurately measured mass of mono-sized latex spheres in the oil (sometimes the spheres are made of glass).

This oil is then tested in the instrument and because the size of the particles is very accurately known, the instrument can be calibrated against known standards. This method is currently gaining a lot of popularity in western Europe and North America. The other method is to use Air Cleaner Fine Test Dust (ACFTD) dispersed in very clean oil. The ACFTD is a naturally occurring dust and the particle size distribution of the dust is known very accurately. From this size distribution an accurate calibration of the instrument can be made.

The main advantage of using ACFTD is that the particles are typical of contaminants and wear metals in hydraulic systems with regard to size and shape.

This is the only method of calibration according to the International Standards Organisation (ISO 4402). The disadvantage of using this method of calibration is that the particles are not uniform (as is the case with a sphere) and the counter will measure size on the basis of the largest dimension.

Because of the Hydroscopic nature of the test dust it is very difficult to prepare the calibrating fluid and it has a limited shelf life. Most importantly, production of ACFTD has been halted and because of this Wearcheck calibrates its instrument with the mono-sized latex sphere method every six months.

Due to the halt in production of ACFTD it seems likely that the International Standards Organisation will eventually adopt the latex sphere method for ISO 4402. It has been shown that there is a linear relationship between the two methods so that either calibration can be adopted. Wearcheck is currently keeping abreast of any changes in calibration techniques for automatic particle counters.

Sampling techniques

Treatment in the laboratory must be standardised.

Finally, some thought must be given to sampling techniques both in the field and in the laboratory.

Obviously the sample container must be scrupulously clean and any external contamination must be avoided, these procedures are actually laid out in the International Standards Organisation method ISO 3722. Treatment in the laboratory must also be standardised and watched very carefully. For example, during transport to the laboratory, most of the contaminants will settle out so the sample must be agitated to get them evenly dispersed in the oil.

At one time it was thought that using an ultrasonic bath to agitate the sample would be an ideal method until it was discovered that the ultra-sound actually breaks up some of the larger particles into smaller particles.

Although automatic particle counters are widely used and provide accurate, repeatable and reproducible results, not all oils are amenable to this test. Oils that are badly oxidised and discoloured may not transmit enough light to give a reliable result or oils that contain water give erroneously high results because the counter "sees" the water droplets as particles.

Some oils actually contain wax particles suspended in them which will also provide a bad result.

What of the future?

As particle counting becomes more accepted as an analytical technique and more OEM's and end-users become aware of the critical importance of contamination control in the hydraulic fluid power industry, the greater the emphasis will be on keeping hydraulic fluids clean.

For warranty purposes, certain manufacturers have already laid down maximum ISO 4406 ratings for the hydraulic equipment and a number of oil companies are concerned that their hydraulic fluid be as clean as is practically possible when dispatched to the customer.

In certain circumstances it has been found that some new oils do not meet the cleanliness requirements of the OEM. This does not mean the oil is not fit for use but the piece of equipment, fitted with a good filtration system, is quite capable of cleaning the oil down to very low ISO 4406 levels as the oil is continuously circulated through the filtration system.

References

1. Day, M.J. Calibration of Automatic Particle Counters.
2. Fitch, E.C.; Hong, I.T. Contamination Control in the Fluid Power Industry.
3. Needleman, W.M. Filtration for Wear Control.
4. ISO - 3722
5. ISO - 4402
6. ISO - 4406.

INTER-NATIONAL STANDARD ISO 4406: 1987 (E)

Hydraulic Fluid Power - Fluids

Method for coding level of contamination by solid particles

0. Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. Hydraulic fluids all contain a certain amount of solid particle contaminants.

1. Scope and field of application

This International Standard specifies the code to be used in defining the quantity of solid particles in fluids used in hydraulic fluid power systems.

2. Reference

ISO 3938, *Hydraulic fluid power - Contamination analysis - Method for reporting analysis data.*

3. Code definition

3.1 General

Most methods of defining solid contaminant quantities are based on the supposition that all contaminants have similar particle size distribution. This supposition may be valid for natural contaminants such as airborne dust, but it is not valid for particles which have been circulated in an installation and subjected to crushing in pumps and separation in filters.

3.2 Basis of Code

The code number corresponding to a pollution level comprises two scale numbers, which permits the differentiation of the dimension and the distribution of the particles as follows:

- the first scale number represents the number of particles larger than 5 µm per ml of fluid;
- the second scale number represents the number of particles larger than 15 µm per ml of fluid.

3.3 Allocation of scale numbers

3.3.1 The scale numbers are attributed according to the number of particles counted larger than 5 µm and 15 µm respectively, yielded in 1 ml of fluid. (See table overleaf)

3.3.2 A step ratio of two, as given between the upper and lower limits for the number of particles per ml in the table, has been adopted to keep the number of scale numbers to a reasonable limit and to ensure that each step is meaningful.

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**INTER-
NATIONAL
STANDARD
ISO 4406:
1987 (E)**

TABLE
Allocation of Scale Numbers

Number of particles per ml		Scale Number
More than	Up to and including	
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1
0.005	0.01	0
0.0025	0.005	0.9