WEAR CHECK® AFRICA
A Division of the Set Point Technology Group

TECHNICAL BULLETIN

ISSUE 16

DEBRIS ANALYSIS

by
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A question often asked is "What is this PQ reading?"

Wearcheck has been producing Technical Bulletins at regular intervals since 1991 and this is now the 16th edition. The topics for publication are usually selected by the Technical Committee and someone is elected to write the bulletin. Over the past 18 months, this procedure has changed slightly and the Technical Committee now selects topics based on the most commonly asked questions coming into the diagnostics department.

Recent issues included synthetic oils, sludging and the perennial wear limits debate. Another question often asked is 'What is this PQ reading?' This presents an excellent opportunity to explain, not just what the PQ is, but to take a look at various techniques that fall under the general umbrella of debris analysis, as some technological changes have recently taken place.

The PARTICLE QUANTIFIER INDEX

The wear readings traditionally encountered in oil analysis are expressed as a percentage, or more commonly as PPM (parts per million) with 1 PPM being equal to 1/10000th of 1% (eg. Fe = 100 PPM). These concentrations are measured with a spectrometer, in Wearcheck's case an ICP (Inductively Coupled Plasma) spectrometer. There is a fundamental limitation to measuring the concentration of wear debris with this technique. Because of the way that these instruments work, particles greater than 8 - 10 μ (micron) cannot be detected. It is obvious that a critical wear situation could exist with large particles present but the iron concentration might be low, i.e. most of the wear particles are greater than 10 μ in size, and would not be picked up by the spectrometer.

The solution to this problem would be to filter all the oil samples through a 10 μ membrane and examine any debris present with a microscope. This practice is highly labour inten-

The PQI is a bulk magnetic index of the oil sample.

sive as it cannot be automated, both in terms of preparing the membrane and having someone look through hundreds of debris pads, as they are called, every day (roughly 1300 per day at Wearcheck). In order to keep costs and turn-around time to a minimum without sacrificing quality, the PQ is used.

The PQI (Particle Quantifier Index) is a bulk magnetic index of the oil sample. The oil sample is shaken and then placed in an instrument that uses a magnetic field which is disturbed by any ferrous (magnetic) material in the sample, irrespective of size. The extent to which the magnetic field is disturbed is proportional to the total ferromagnetic content of the oil. The PQ is a unitless number but it is quantitative and can be trended. The higher the number, the more ferrous debris present. If the PQ had units, they would be related to the magnetic inductance of the sample, probably Webers per square centimetre. Attempts have been made to correlate the index with an actual concentration value such as milligrams of iron per litre of oil but, because different steels have different magnetic inductances, this has met with limited success.

Although the PQ is a quantitative measurement, the laboratory uses it as a screening test. If the PQ is over a certain failure limit, the oil is filtered through a 5 μ membrane (pad) and any debris present is examined under a microscope. A qualitative description of the debris is given in the diagnosis.

The failure limits depend on the type of component from which the oil has come. As an example, a hydraulic system runs far more delicately and cleanly than a conveyor gearbox and what is acceptable for the gearbox would indicate catastrophic wear in the hydraulic system. The failure PQ for the hydraulic system is 25, for the gearbox 230. These failure limits have been determined from correlation studies of tens of thousands of samples where both a PQ and an MPE (Microscopic Particle Examination) have been carried out. The PQ of every oil sample is measured at Wearcheck and approximately 20% of the samples fail the screening test. Of these 20%, roughly half of the MPE's carried out show no abnormal wear debris; this shows that the screening limits are kept very tight.

Although the laboratory uses the PQ as a screening test, the diagnostics department looks at it in a quantitative manner. A normal wear profile (see Graph 1) should show a large number of small wear particles and few large ones. As abnormal wear starts to take place, this profile will shift to a greater number of larger wear particles. It is possible for the iron reading to level out or even decrease, because of the size limitation and filtration, whilst the PQ starts to increase in an abnormal wear situation (see Graph 2).

In the case of non-magnetic wear material such as white metal, aluminium or copper/brass/bronze, it is very unusual to find a non-ferrous metal wearing against another non-ferrous metal. Iron and steel tend to be the major wearing elements in all mechanical systems. Often, non-magnetic material becomes impacted with the ferrous wear debris during the wear process so even non-magnetic material is detected by the PQ.

If a failure occurs and the particle count is too high, this might be grounds for the rejection of a warranty claim.

PARTICLE COUNTING

Another debris detection technique is particle counting, commonly known as the ISO 4406. All tests carried out in the laboratory are concerned with measuring the concentration of a known entity, eg. how much water or iron is present, or the viscosity of the oil. Particle counting, however, looks at 'how many' and 'how big' without concerning itself with what the particles are actually made of. They could be anything: iron, copper, dust or, in KwaZulu-Natal, wood chips and sugar cane. In effect, the particle count gives a measure of the cleanliness of the oil.

Particle counting is only carried out on what are traditionally called clean oil systems: hydraulics, pumps, compressors, turbines and automatic transmissions. These are the systems that are sensitive to particulate contamination. Depending on which body of research is read, 70 to 85% of all hydraulic system failures are due to particulate contamination, with 90% of these failures being due to abrasive wear.

This test has become so important that certain OEM's (Original Equipment Manufacturers) have set upper limits on the cleanliness levels for the oils used in their hydraulic systems, insisting that the oil be monitored on a regular basis. If a failure occurs and the particle count is too high, this might be grounds for the rejection of a warranty claim. Unfortunately, getting these limits out of most OEM's can be difficult, if not impossible. Wearcheck is often asked what an acceptable contamination level is, but this can only be determined by the manufacturer of the equipment.

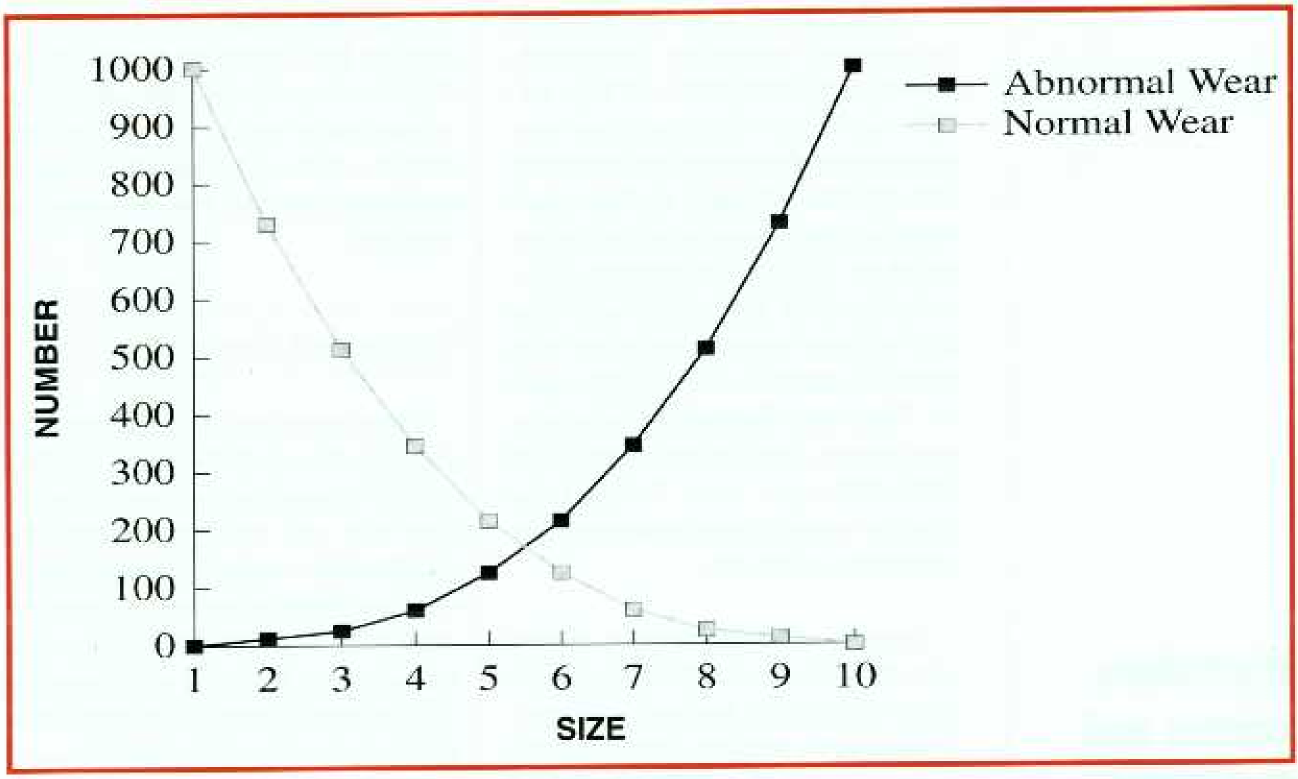
Although the concept of particle counting is straightforward, the mechanics of carrying out the test are fraught with controversy, so much so that the ISO (International Standards Organisation) has had the whole procedure under review for most of this decade. Let's examine where these problems arise and how they may be resolved.

Different methods

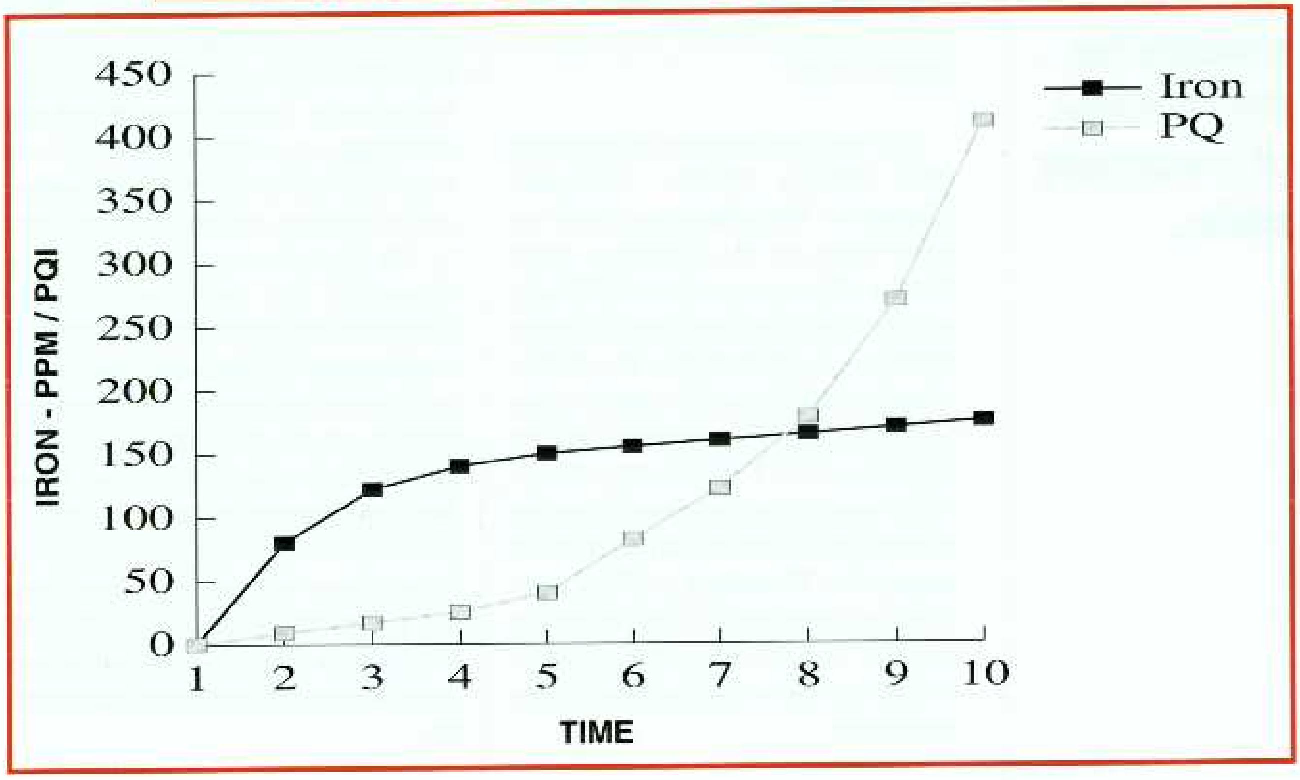
There are two basic methods for carrying out a particle count on an oil sample: manual and automatic. In this day and age of high production requirements, manual counting methods have fallen into disuse as they are very time consuming and prone to human error. With this technique, the oil is filtered through a membrane of known pore size, the particles are counted manually under a microscope over a small area and the results extrapolated for the whole sample.

Automatic particle counters have been around since the early 1960's and fall into two main sub-divisions, light blockage and filter blockage techniques. In the **light blockage technique**, a small sample of the oil is passed between a laser light source and a detector, and the shadows cast by the particles on the detector are measured. The signals sent by the detector are processed through a sophisticated mathematical modelling programme and result in a number of particle counts per millilitre of oil in various size ranges. With the **filter blockage method,** a larger volume of oil is passed through a mesh of known pore size and the time taken for the mesh to block is measured. The particle count is then determined from a standard size distribution profile.

Graph 1
PARTICLE DISTRIBUTION PROFILE



Graph 2
IRON AND PQ READINGS, OVER TIME



Different calibrations

The two instruments used in automatic particle counting have to be calibrated and there are two ways of doing this. Both methods use an oil that has particles dispersed in it of a very accurately known particle size distribution. One method uses latex spheres - because of their spherical symmetry, it does not matter what orientation they take when they are presented to the laser detector or flow through the mesh. The objection to this calibration technique is that particles in the real world are not all perfectly spherical. The other method of calibration is to use ACFTD (Air Cleaner Fine Test Dust). This is dust that is actually swept out of the Mojave Desert in the United States, but has a very consistent size distribution profile. The argument against this calibration method is that particle orientation now becomes important.

Wearcheck uses real world particles for calibration.

So, we now have three methods of particle counting and two methods of calibrating the instruments, resulting in five possible ways of determining oil cleanliness (manual counting is absolute and is not calibrated as such). All well and good - it is nice to have so many options - but problems arise because all five techniques will give different results, not radically so, but enough to cause confusion. Furthermore there is no direct correlation between the methods.

At this point in time all combinations are used and accepted which is fine as long as only one laboratory is used (good repeatability) and a trend can be established. However, when other laboratories come into the picture (poor reproducibility), different combinations of methods may be used and then discrepancies will occur. Neither system is entirely wrong, neither system is entirely right. Wearcheck uses the light blockage instrument calibrated with ACFTD which is the preferred, but not officially sanctioned, method.

There are as many pros as cons for whichever combination is selected. The method Wearcheck uses has the advantages of using real world particles for calibration and an instrument that measures actual size ranges rather than assuming a typical distribution profile. The disadvantages are that particle orientation becomes important and heavily coloured oils cannot be analysed accurately, neither can oils contaminated with water (the detector sees water droplets as particles).

The solution

The ISO has finally standardised a calibration method for automatic particle counters (under ISO 11171, also called ISO MTD for Medium Test Dust). This standard is also traceable which means that it is suitable for laboratories operating under a quality management system such as ISO 9000. This, however, is not the end of the story.

Many people are familiar with the term ISO 4406 for a particle count. The procedure laid down under ISO 4406 gives an easily understandable method for expressing fluid cleanliness. Wearcheck measures the total number of particles per millilitre of oil in eight size ranges: 5-10 micron, 10-15 micron, 15-20 micron, 20-25 micron, 25-50 micron, 50-75 micron, 75-100 micron and greater than 100 micron (1 micron = 1/1000th of a millimetre).

For most oils these numbers are frighteningly large and it can be very

International 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

Wearcheck's service will in most cases give the same answer as an official ISO 4406.

difficult to determine how much cleaner or dirtier one oil may be from another. What ISO 4406 does is to count all particles greater than 5 µ and assign a range number to that value, then count all particles greater than 15 µ and assign another range number. So instead of looking at eight different and difficult to comprehend numbers, ISO 4406 gives a cleanliness index of two numbers such as 18/15 that would be dirtier than 17/13 for example. This system is much easier to understand.

The table on the opposite page shows how these numbers are determined. A common misconception about these range numbers is that the first number only counts the number of particles between 5 and 15 µ when, in actual fact, it counts all the particles greater than 5 µ. These two ranges have been chosen because the first number gives a general silting index of the oil and the second number is more indicative of abnormal wear and/or contamination.

Some cleanliness measurements give a three-number index, eg. 20/17/14 where the first number indicates all particles greater than 2 µ. Up until now this has never been officially sanctioned by the ISO and recent research has shown that most automated particle counters are not sensitive enough to provide accurate particle counts at such a small size.

Problems arise because there is no direct or linear correlation between calibration with ACFTD and MTD. The reasons for this are quite complex but the differences between the two systems are shown in the table - above right.

OLD ACFTD	NEW MTD
2 µ	4 µ
5 µ	6 µ
15 µ	14 µ

This will mean that the new calibration system will show fewer particles at the 2 and 5 µ level and more particles at the 15 µ level. The differences are slight but are once again non-linear and, when the new calibration method comes into effect, trends will appear to change slightly. This, however, will result in better resolution of the test.

The Wearcheck report gives a two-number cleanliness ratio, measuring particles greater than 5 and 15 µ (the 2 µ is not measured) but does not call it an ISO 4406, and there is a very good reason for this. ISO 4406 only governs how the numbers are assigned while other ISO documents, such as ISO 4402 and 4572, make up a very complex procedure which governs how the bottles are produced (only glass can be used), how the sample is taken, and the number of times the test must be done in the laboratory. The sampling procedure is beyond the capabilities of most workshops and the production and quality control of the sampling bottle as well as the analytical technique in the laboratory would push the price of the test beyond the budget of most people.

The service that Wearcheck provides is affordable and in most cases will give the same answer as an official ISO 4406 but, because not all the procedures are strictly adhered to, it would not be technically correct to call the numbers quoted an ISO 4406 cleanliness rating. The procedure that

Wearcheck uses is 'based upon but not conforming to' ISO documentation, a wonderful phrase that allows strict quality control for situations adapted to local conditions and needs.

RPD ferrography

Another technique in Wearcheck's arsenal of tests is RPD (Rotary Particle Deposition) ferrography, which is supplementary to the normal tests carried out in the laboratory. An oil sample from a stationary industrial gearbox that goes through the standard battery of tests may show a high iron concentration and a high PQ, and the MPE (Microscopic Particle Examination) may show excessive visible debris under the microscope indicating a severe wear situation. All of this can be taken one level deeper with RPD ferrography which involves the removal of ferrous debris from the oil.

RPD ferrography involves the removal of ferrous debris from the oil.

This debris is deposited on a small, square, glass slide that rotates in a magnetic field. The debris is separated by the magnetic field and flow decay into three distinct bands based on particle size. Once the slide has been dried, it can be examined under a powerful compound microscope with the ability to resolve debris down to 1 μ in size (the typical width of a human hair is about 40 μ). Using special lenses, filters and lighting techniques, the morphology of individual wear particles can be determined.

Size and concentration are still important but properties such as surface texture, edge and outline detail and colour can be examined. This leads to the identification of various wear modes such as cutting, sliding, rolling and rubbing wear, all of which have different causes. It also means that it is possible to distinguish between such things as gear and bearing wear as the two types of particles appear very different when examined on an individual basis.

The PQ, MPE, particle count and RPD ferrography make up the techniques employed when oil analysts refer to debris analysis. They cover a wide range of situations that would not have been identified by traditional spectrometric analysis, a technique that has been in use for more than 50 years. As with many other disciplines, technological advances are being made all the time in the field of oil analysis.

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Produced by the Wearcheck Division of Set Point Technology

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