From Micro to Macro: a Two-Stage Knowledge-Based Approach to Wear Debris Analysis for On-Site Condition Monitoring

This paper sets out an innovative, two-stage knowledge-based approach to wear debris analysis for on-site equipment health monitoring, which is complimented by the **V4L** ***Micro*-2-*Macro*** hardware and software kit. This new approach takes account of the following:

- **The need for a two stage approach** arises because conventional laboratory oil testing has become less useful for machine health monitoring. This is due to the advent of improved lubricant formulations and more efficient filter designs, which either remove or significantly delay the appearance of standard, data-driven condition monitoring alert signals from in-service lubricant samples.
- **First stage routine monitoring is of microscopic debris** and uses the latest **V4L** computer vision technology to analyse fine debris in order to extract previously inaccessible, important visual cues from images of particles as small as 5 microns. Abnormalities in the fine debris then trigger early warning alerts to activate the second stage diagnostic analysis.
- **Second stage diagnostic analysis is of macroscopic debris** extracted from in-service filters or magnetic plugs. This uses the **V4L CADET** knowledge-base for wear debris identification and the associated five level severity rating advocated by the ASTM D7684-11 standard guide to inform timely and appropriate maintenance action, which can help to avoid costly false alarms or critical unscheduled down-time.
- **The ideal place for equipment health monitoring is on-site** where engineers can use their extensive knowledge of the equipment to put condition monitoring data and information into the context of maintenance schedules and real-time data: speeds, loads, temperature and oil pressure or unusual operating conditions. Use of the **V4L** ***Micro*-2-*Macro*** kit combined with on-site engineering skills and experience offers a cost effective on-site diagnostic capability to rival that of most specialist labs.

By *V Leavers*

Director
V4L Particles Ltd, 59-60 Thames Street
Windsor SL4 1TX, United Kingdom
Tel: +44 1753 27-20-90
enquiries@V4L-group.co.uk
www.V4L-group.co.uk

From Micro to Macro: a Two-Stage Knowledge-Based Approach to Wear Debris Analysis for On-Site Condition Monitoring

Why conventional lubricant testing needs rethinking

Technological advances in lubricant formulations and more efficient filter designs should logically have made equipment health monitoring easier. However, this is not the case if monitoring is restricted to conventional oil and debris analysis methods. This is because:

- **Innovative high-performance additives and improved synthetic base oils** are more chemically stable and robust. Provided they are used properly and not allowed to become contaminated in storage or use, they should give reliable service. This means that, for most machines, standard laboratory oil tests are only useful to confirm that: the equipment was filled with the correct grade of oil; the correct grade of oil was used for top-ups; and the oil left in the machinery has not become contaminated and/or exhausted.

- **Modern in-service lubricants are less likely to reveal machine wear problems** when tested by standard laboratory methods such as viscosity, TAN/TBN, etc. This is because they are chemically more stable and are less affected by overheating or abnormal wear, than previous lubricant formulations.

- **Despite better lubricants, wear still occurs** and wear debris particle monitoring remains the best way to detect faults in lubricated machinery. However, improved filter designs now trap large wear and contaminant particles more efficiently, leaving fewer in the lubricant to analyse by methods such as ferrography.

How does two-stage wear debris particle analysis work?

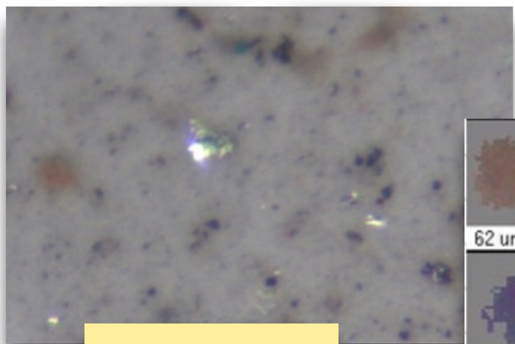
To-date it has been the accepted wisdom that it is not possible to extract condition monitoring information from images of particles smaller than 20 microns other than to size and count them. **V4L**'s dedicated research has produced advances in computer vision technology that now allow important visual information to be retrieved from images of microscopic particles as small as 5 microns.

First stage routine testing of microscopic debris uses V4L's state-of-the-art computer vision technology

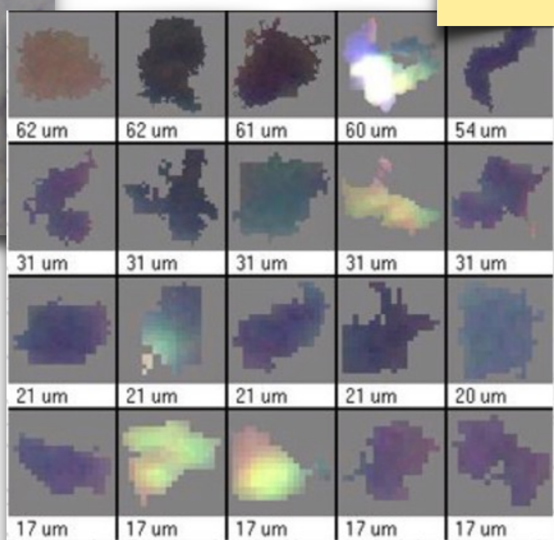
V4L's novel image processing algorithms have been incorporated into **FilterPatchScan**, unique plug-and-play particle sizing and counting software. This allows previously inaccessible, important condition monitoring information to be extracted from images of particles as small as 5 microns. The software does this by detecting and amplifying important visual cues such as colour and shape. Detectable abnormalities might include: a significant increase in the number of particles <6 microns coupled with the appearance of corrosion particles; evidence of contamination by mineral particles coupled with fine cutting wear or the appearance of fine temper coloured particles.

By way of an illustrative example, the following items were recorded in the first stage report for a gearbox:

Particle sizing and counting	19/18 ISO 4406 is within the 20/19 alert level
Patch test observation	Fine, temper-coloured wear particles
History	First startup since gearbox drained, uninstalled, transported, reinstalled and refilled
Comments	Higher than usual amounts of benign debris were seen. This is normal following transit and reinstallation. However, a large percentage of fine, temper-coloured wear particles were also seen, indicating abnormal wear and local heating
Recommendations	Current condition requires removal of the oil filter for immediate further investigation



FilterPatchScan test image



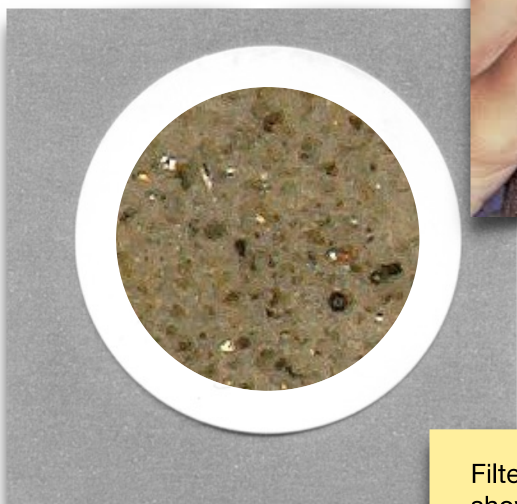
FilterPatchScan tile images

Second stage analyses wear debris from oil filters or magnetic plugs

Once the second stage analysis is triggered by abnormalities in the microscopic wear debris the in-service filter or magnetic plug is removed and the larger, macroscopic wear debris particles are extracted for further analysis. The following items were recorded in the second stage report for the gearbox:

Action	Oil filter removed and trapped wear debris particles recovered and analysed
Filter debris observations	Large, steel-coloured fatigue wear particles together with temper-coloured reworked particles
History	First startup since gearbox drained, uninstalled, transported, reinstalled and refilled
Comments	Misalignment of rolling element bearing diagnosed. This is probably due to damage sustained during transit
Recommendations	ASTM D7684-11 severity level 4 – Serious Fault – requiring removal from service for repair

Large wear particles trapped by the oil filter element

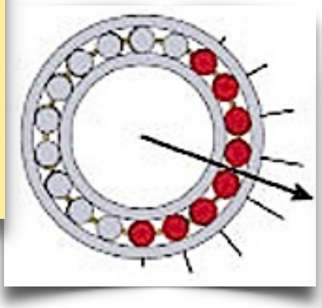


Filter patch showing oil filter debris

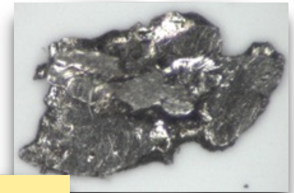
V4L CADET case studies library supports on-site diagnoses

V4L CADET software, included in the **V4L M***icro***-2-M***acro* kit, quickly brings on-site technicians up to speed with ASTM D7684-11 compliant wear debris analysis:

Misalignment in rolling element bearings causes uneven cyclic loading which can exceed the design parameters of the bearing components and materials, eventually leading to failure.



Initially the cyclic loads may be insufficient to break the oil film. They are transmitted hydraulically to the metal surfaces, causing fatigue micro-cracking and spalling of the inner and/or outer rings and the balls/rollers.



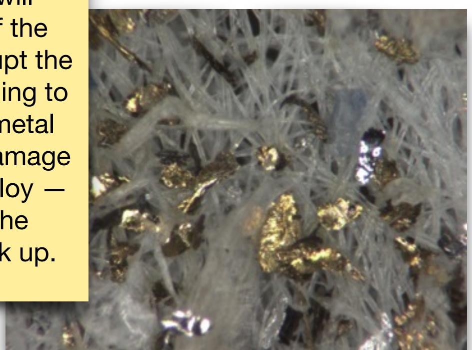
Large fatigue wear particle

The particles produced by the fatigue wear vary in size and number according to the size and speed of the bearing; the load; the metallurgy of the materials; and the type and extent of the misalignment.

Reworked fatigue wear particle

Some of the particles will show direct evidence of fatigue micro-cracking, while others will be reworked and flattened by entrainment in the rolling contact of the bearing. Reworking causes local overloading and further fatigue damage to the bearing surfaces.

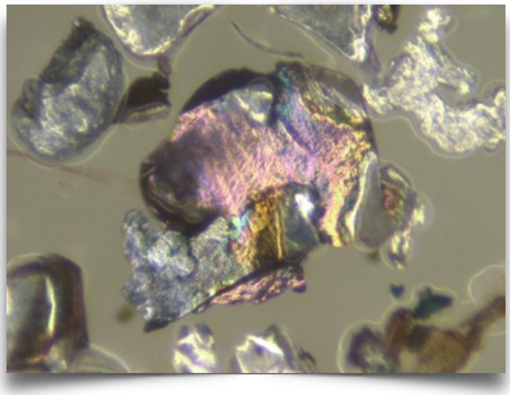
If unchecked, the damage will cascade. Surface scarring of the rings and balls/rollers will disrupt the oil flow within the bearing leading to loss of lubrication, metal-to-metal contact and adhesive wear. Damage to the cage — often copper alloy — will also occur. Eventually the bearing will overheat and lock up.



Why use two-stage wear debris particle analysis?

The two-stage approach takes account of the step change in lubricant formulations and filter design and meets the various challenges posed by on-site condition monitoring in the following ways:

- **Advanced wear debris analysis does not rely on the interpretation of sets of numbers,** rather it is knowledge-based, delivering condition monitoring information rather than simply numerical data. It can distinguish temporary and on-going wear situations in a way that conventional oil monitoring cannot. For example tempered steel particles are symptomatic of lubrication starvation, misalignment or heavy loading. The onset of these conditions can be seen in the fine debris particles before it is evident in the numerical data delivered by standard TAN or viscosity tests. This is because local wear conditions do not usually generate sufficient heat to oxidise the bulk of the lubricant and will therefore not be detectable by standard laboratory tests until the condition is well advanced. Trending of the percentage of fine tempered particles can help to distinguish between transient and on-going wear conditions.



- **Fewer False Alarms and Critical Failures.** Standard laboratory oil testing produces sets of numbers that may be difficult to interpret in relation to maintenance action. Moreover, changes in the various oil test results may lag behind the onset of the wear condition. This can lead to a simple stop/go maintenance strategy in which costly false alarms are unavoidable. The **V4L M***icro***-2-M***acro* two stage approach uses visual cues associated with both the microscopic and macroscopic wear particle debris to determine the root cause of the problem and this will inform timely and appropriate maintenance action. This can help to avoid costly false alarms when equipment is taken out of service before it is necessary or perhaps more importantly stop equipment from being left in-service when it is critical, which in some industries can lead to fatalities.

- **Less unscheduled downtime.** When large, critical equipment situated in remote, harsh environments fails unexpectedly it can take many weeks to arrange to repair or replace it. For this reason advance warning of necessary maintenance or replacement can offer significant savings and avoid the losses incurred by avoidable, lengthy deferred revenue situations due to halted production. For example when an unforeseen critical equipment failure causes an oil rig to stand idle. The **V4L M*icro*-2-M*acro*** two stage approach can help to determine not only the root cause of an equipment problem but also the appropriate maintenance action according to the five level severity rating advocated by the ASTM D7684-11 standard guide thus avoiding the heavy losses associated with unscheduled critical equipment down time.

What's in the V4L M*icro*-2-M*acro* kit?

V4L recognizes that maintenance professionals often prefer a one-stop-shop approach to sourcing equipment and for this reason provides a comprehensive package that caters to all of the needs of the on-site technician with respect to sample analysis and diagnosis. However, the kit is modular and items can also be acquired separately. The complete kit consists of the following modules:

- **V4L M*icro*-2-M*acro* imaging hardware** that is rugged, compact and portable with unique plug-and-play **FilterPatchScan** software for particle sizing, counting and analysis together with detailed sample preparation and analysis instructions.
- **V4L C*omputer* A*ided* D*ebris* E*valuation* T*raining* (CADET) software**, which quickly brings on-site maintenance professionals up to speed on wear debris analysis, whilst at the same time supporting them in their diagnoses.
- **V4L Mini-Lab** containing all of the equipment necessary for filter patch making together with a complete set of the required dry consumables.

The complete kit packs down into flight cases for easy transportation.

For more information please contact enquiries@V4L-group.co.uk