THE ROLE OF LUBRICANT CONDITION MONITORING IN MAINTENANCE PROGRAMMES

The term Condition Monitoring (CM) is understood by most in the lubricants industry to refer to the periodic analysis of a lubricant in order to monitor both the levels of additive and also, more importantly, the levels of contaminants in the lubricant. In fact, the scope of true CM is much wider, and can include e.g. vibration monitoring, thermography, ultrasonic analysis, filter wear debris analysis, ferrography, dye penetration, radiography, etc.

This article will concentrate on lubricant CM, but firstly it would be as well to briefly review the historical development of maintenance practices over the years, which will also help to establish the relevance of lubricant CM.

It should be stressed that each piece of equipment should be treated on its own merits with regard to the application of the most suitable type of maintenance philosophy.

BREAKDOWN MAINTENANCE
This involves rectification only after the failure of an item of equipment. Although no longer viable for large, costly and critical items of equipment, breakdown maintenance can still be appropriate for small, non-critical items, e.g. light bulbs.

PREVENTIVE MAINTENANCE
This involves the servicing, overhaul and replacement of items based on intervals of operating time or other unit, or on an elapsed time basis, the most familiar example is probably the servicing of your car. The downside to this philosophy is that units of equipment which are possibly operating completely satisfactorily can be unnecessarily disturbed, and there can be wastage involved when items are prematurely scrapped.

PREDICTIVE MAINTENANCE
This is where CM first came into its own when maintenance was carried out on items based on predicted needs rather than on a regularised basis.

PROACTIVE MAINTENANCE
This system developed from the previous three philosophies and is concerned with the analysis of all maintenance and CM techniques to determine the causes of failures, and their prevention. As could be expected, these differing maintenance philosophies result in differing failure modes. These are summarised below in order of decreasing seriousness:

CATASTROPHIC FAILURE
As the name implies, this is the sudden and complete failure of a piece of equipment, and is associated with the 'Breakdown Maintenance' approach.

PREVENTIVE FAILURE
A state of deteriorating performance leading to a gradual loss of efficiency and/or a progressive shortening of working life of some, but not necessarily all, components.

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PROACTIVE FAILURE
This is where the use of maintenance and free from contamination.

LUBRICANT CONDITION MONITORING
The various approaches to CM outlined above, lubricant CM is one of the most useful, and can play an important complementary role in both Predictive and Proactive maintenance philosophies. However, it must be stressed at this point that lubricant CM should not be viewed as the complete answer to every potential failure situation. Even with a lubricant CM programme, catastrophic failures can still occur in a number of situations. These include:

EXTREME SHOCK LOADING
Examples are driver abuse and overloading in the case of vehicles

MEdAL FAlTlGUE
Lubricant CM will not identify the progressive breakdown in the crystalline structure of metal components, which could lead to their eventual breakdown.

SHORTAGE OF LUBRICANT
If a piece of equipment, such as an engine, runs short of oil, irreversible damage will occur, which will not be rectified by subsequently topping up the oil level. Failure to properly rectify a previous breakdown situation can result in the generation of wear debris, which, if not completely removed, can result in further failures of other components in the same piece of equipment. Also, generally speaking lubricant CM should not be used in isolation, but in conjunction with other monitoring programmes including filter debris inspection.

IDENTIFICATION OF AN APPROPRIATE LUBRICANT CM PROGRAMME
Lubricant CM programmes are developed according to the type of equipment using the lubricant. Programmes generally fall into the following broad classes:

- Engines
- Gear Systems (including automotive manual gearboxes and differentials, also industrial gearboxes
- Automatic Transmissions
- Hydraulics
- Compressors and turbines
- A number of further but more minor categories include e.g. aircraft engines, refrigeration compressors, etc.

A normal test programme would include
- Elemental analysis
- Particulate analysis (normally quantification only)
- Viscosity measurement
- Water content

(Continued on Page III)
### TABLE 1. COMMON ELEMENTS DETECTED BY ICP AND THEIR RESPECTIVE SOURCE

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Found in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>Gears, rolling bearings, cylinder liners, shafts</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr</td>
<td>Rolling bearings, piston rings</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>Rolling bearings, camshafts and followers, thrust washers, valve stems, valve guides</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>Piston rings, soluble additives, solid additive</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Al</td>
<td>Pistons, journal bearings, dirt</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Brass/bronze bushes, gears, thrust washers, oil cooler cores, internal coolant leaks</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn</td>
<td>Bronze bushes, washers and gears</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
<td>Journal bearings, grease, contamination from leaded petrol</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>Silver solder</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>Dirt, grease, additives</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>Internal coolant leaks, additives, sea-water contamination</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>Grease</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>Additives, sea-water contamination</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>Additives</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>Additives</td>
</tr>
<tr>
<td>Boron</td>
<td>Bo</td>
<td>Additives, internal coolant leaks, brake fluid contamination</td>
</tr>
<tr>
<td>Sulphur</td>
<td>S</td>
<td>Mineral oils, additives</td>
</tr>
</tbody>
</table>

### TABLE 2. COMMON WEAR SITUATIONS AND THEIR IDENTIFICATION USING ICP

<table>
<thead>
<tr>
<th>Situation</th>
<th>Elemental analytical results by ICP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dirt entry</td>
<td>Si and Al present, usually in the ratio between 2 and 10 to 1. Monitor trends for increases and also for increases in associated wear elements</td>
</tr>
<tr>
<td>Piston torching</td>
<td>Al and Si present in ratio 2 to 1. Since failure is rapid, this type of failure is rarely detected in time by CM.</td>
</tr>
<tr>
<td>High Fe (alone)</td>
<td>Varied sources commonly include valve gear, oil pump wear, and rust</td>
</tr>
<tr>
<td>High Si (alone)</td>
<td>From anti-foam additives, grease and silicone sealants</td>
</tr>
<tr>
<td>Top-end wear (engines)</td>
<td>Increases in Fe, Al and Cr. Presence of Ni also indicates camshaft/cam follower wear</td>
</tr>
<tr>
<td>Bottom-end wear (engines)</td>
<td>Increases in Fe, Pb, Cu, Sn</td>
</tr>
<tr>
<td>Overheating</td>
<td>Increases in Mg, Ca, Zn, P, S (all from additives) and viscosity due to loss of volatile oil components</td>
</tr>
<tr>
<td>Bronze bush wear</td>
<td>Increase in Cu and Sn normally in ratio of 20 to 1</td>
</tr>
<tr>
<td>Bronze gear thrust bearing wear</td>
<td>Increase in Cu and Sn normally in ratio of 20 to 1</td>
</tr>
<tr>
<td>Internal coolant leak</td>
<td>Increases in Na, B, Cu, Si, Al and Fe (not necessarily all) and possibly Pb, Cu and Sn</td>
</tr>
<tr>
<td>Rolling bearing wear</td>
<td>Increases in Fe, Cr and Ni, possibly also Cu from brass/bronze cages</td>
</tr>
<tr>
<td>Hydraulic ram wear</td>
<td>Increases in Fe, Cr and Ni</td>
</tr>
</tbody>
</table>

### TABLE 3. IRON AND PQI RELATIONSHIP

<table>
<thead>
<tr>
<th>Situation</th>
<th>ICP Fe content (ppm)</th>
<th>PQI</th>
<th>Inference</th>
<th>Wear Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>Low</td>
<td>Few wear particles</td>
<td>Normal wear profile</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>Low to medium</td>
<td>Lots of small particles, few large particles</td>
<td>Accelerated wear. Wet brake systems. Dirt entry</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>High</td>
<td>Few small particles, many large particles</td>
<td>Metal fatigue</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>High</td>
<td>Lots of particles of all sizes</td>
<td>Serious wear indication with possibility of catastrophic failure</td>
</tr>
</tbody>
</table>

### TABLE 4. INTERPRETATION OF CHANGES IN VISCOSITY

<table>
<thead>
<tr>
<th>Component</th>
<th>Viscosity Change</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Increase</td>
<td>Overheating, Sludging, Fuel dilution (Heavy fuel oil-powered marine engines only)</td>
</tr>
<tr>
<td>Engine</td>
<td>Decrease</td>
<td>Viscosity Index Improver breakdown in multigrade oils</td>
</tr>
<tr>
<td>Other Components</td>
<td>Increase</td>
<td>Overheating, Grease contamination, Severe water contamination, Breakdown of the oil, Mixture of oils</td>
</tr>
<tr>
<td>Other Components</td>
<td>Decrease</td>
<td>Contamination by volatile substance, Viscosity Index Improver breakdown in multigrade oils, Breakdown of the oil</td>
</tr>
</tbody>
</table>

### TABLE 5. TYPICAL WATER LIMITS

<table>
<thead>
<tr>
<th>Component</th>
<th>Limit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>0.0</td>
</tr>
<tr>
<td>Drivetrain</td>
<td>1.0</td>
</tr>
<tr>
<td>Transmission</td>
<td>0.5</td>
</tr>
<tr>
<td>Hydraulics</td>
<td>0.5</td>
</tr>
<tr>
<td>Compressors</td>
<td>According to type</td>
</tr>
</tbody>
</table>
1. ELEMENTAL ANALYSIS
This aspect of the CM monitoring programme yields the most information and is carried out using spectroscopic examination, normally Inductively Coupled Plasma Spectroscopy (ICP). The technique does have its limitations, however. The method is limited to detecting elements or which are in solution or in very fine particulate form only, i.e. less than 5-8u. In practice, this is a very real limitation, since components which are undergoing the initial stages of failure through metal fatigue will generate particulate matter from spalling which is larger than can be detected by ICP.
Also, because the technique only measures elemental concentrations, and not the nature of the compound containing the element, the technique will not necessarily assess the extent of additive depletion in a lubricant. Examination of an engine oil containing a calcium-based detergent, for example, will show unchanged levels of calcium concentrations even though the calcium-based additive has undergone a change from an active form to an inactive form.
The elements determined are grouped into three main categories, i.e.:
- Wear Metals
- Contaminants
- Lubricant Additives
See Tables 1 and 2.

2. PARTICULATE QUANTIFICATION
This analysis can take many forms, from a simple quantification of the total amount of magnetic material present (Particulate Quantification Index - PQI) to a full assessment of the numbers of particles present, their sizes and even their shapes.
Application of the more sophisticated techniques of particle counting and sizing is not normally necessary for conventional lubricant CM, however, where generally a measurement by magnetic sensor indicating the total amount of Fe present is all that is required, since this information can also be used in conjunction with the ICP Fe measurement to provide further information on the distribution of wear particles.

WHAT THE UK’S NATIONAL MEASUREMENT SYSTEM (NMS) CAN DO FOR YOUR BUSINESS
Over 80% of the world's trade in manufactured goods involve measurement at some point the manufacturing process.
Quote from a Multi-national car manufacturer in the UK. "If you can't measure it you can't manage it."

Improving the accuracy of measurements of sulphur in fuel is expected to cut production costs by about £4m per annum.

In the UK alone it is estimated that there are 10 million blocks and length bars in use, all of which need calibrating to establish their true size.
Measurement in the UK contributes significantly to the UK economy, directly and indirectly underpinning and enabling about 0.8% of GDP per annum or £5 billion per annum.

NMS supports business in a whole variety of ways:
- raising productivity through improved process and quality control
- ensuring barrier-free trade through the concept of 'once measured, accepted everywhere', including overseas
- contributing to the development of existing and new products and processes
- confident compliance with statutory and regulatory requirements
- improving quality of life of UK citizens by providing confidence in health and safety
All of which improves UK competitiveness and impacts on your business's bottom line - through greater efficiencies, reduced wastage, compliance with regulation and increased profit margins. Measurement also underpins a wide range of other activities, including environmental controls, safe medical treatment and food safety regulation.

What is the NMS?
The National Measurement System (NMS) provides world-class measurement standards and calibration facilities. These enable UK businesses and public authorities to make accurate measurements, which are nationally and internationally accepted.

A WORLD WITHOUT MEASUREMENT
At the start of the 20th century, 1,206 different combinations of nuts and bolts that were supposedly the same size were tested, but only 8% of them 'engaged sufficiently' to allow tightening with a spanner.
Such inconstancies are hard to imagine in today's cost-driven, competitive market.
Once measured, accepted everywhere
Certification and testing requirements vary from country to country. When certification and testing are statutory or regulatory requirements they can create barriers to trade. The NMS supports international mutual recognition arrangements - through the foundation of accredited certification, calibration and inspection - which reduces the need for UK suppliers to be assessed by each of their customers and so helps reduce trade costs.
GOVERNMENT ADVICE TO BUSINESS: ACTIONS TO TAKE BEFORE AND DURING A STRIKE IN THE FIRE SERVICE

This is a synopsis of the guidance advice on the practical implications for businesses and their employees and was issued by the Office of the Deputy Prime Minister.

The UK Fire Brigades Union (FBU) has announced that there will be strikes within the Fire Service, though at time of going to press latest negotiations have deferred some of the strike-days.

The owner or operator of a building (not the fire brigade) is responsible for safety on site and emergency evacuation arrangements. Employers should therefore check their preparedness and review their contingency arrangements accordingly.

During any strikes, the Ministry of Defence will provide emergency fire and rescue cover as part of national contingency arrangements. The 999 system will continue to operate with calls being diverted on a temporary basis to alternative operations centres. From there, emergency fire crews and other specialised teams will be mobilised from temporary fire stations. Military fire crews are trained and equipped to carry out basic fire-fighting and rescue operations. They will not have the same capability as your local fire brigade and they are more widely dispersed. Businesses and other organisations should consider what additional measures they can put in place to prevent fire and limit damage.

From a health and safety perspective, it is anticipated that the vast majority of businesses will be able to continue their commercial activities unaffected by the dispute. However, during periods when the fire services are on strike, it is foreseeable that:

• Attendance times to some incidents will be increased.
• The emergency services attending will have fewer specialised capabilities.
• The emergency services attending will be familiar with neither the incident site concerned nor the local geography.

Accordingly, businesses should consider the implications of, and risks associated with, the potentially reduced emergency services response and where appropriate institute supplementary measures and arrangements to prevent incidents and minimise the consequences of reduced emergency response cover. Examples of such measures include, where possible, delaying certain activities if they have an increased risk of fire associated with them; rescheduling deliveries of flammable substances to coincide with periods when full emergency response cover is available when or lowering inventories of substances/items that are flammable or toxic. However, businesses should ensure that such measures do not increase the risks of an incident of another nature; for example, delaying the welding of a pipe decreases the risk of fire but might result in the collapse of the weakened pipework.

DIRECTORS AND MANAGERS RESPONSIBILITIES

The Health and Safety Commission's recent guidance on the responsibility of directors and the guidance on internal control issued following the Turnbull Report affirm the importance of risk management.

The responsibilities of directors and management boards will include the identification of any increase in risk to their core assets or business operations that may arise out of the dispute and taking appropriate steps to manage the risk.

Normal evaluation of the risk from fire is based on the presumption of an early and defined attendance by fully trained and equipped fire-fighters. This cannot be guaranteed for the duration of any strike action and there will be an increase in the level of risk. Briefings for senior staff, review of risk assessments and validation of emergency response information are key features in preparation and response during the dispute.

Directors' Checklist
• Have the risks from fire been properly assessed and prioritised? Do these include risks to assets and business as well as risks to safety?
• Is there an Incident Control Team to manage any emergency situation and limit damage?
• Is there a Business Recovery Plan in place and is it up to date?
• Are key records, emergency plans and contact details duplicated off site?
• Have all existing fire precautions been specifically checked to ensure readiness?
• Is there a detailed emergency fire procedure in place? Is this up to date and has this been brought to the attention of all staff?
• Are all key staff aware of their duties and have they been properly trained?
• Have steps been taken to increase security patrols or management inspections to deter fire raising and improve housekeeping?
• Are arrangements in place (during periods of strike action) to call the fire service by using the 999 system rather than placing reliance on automatic systems?

EMPLOYEES' RESPONSIBILITIES

The best protection against such a risk remains, as ever, the vigilance of everybody who works in a building observing the usual health and safety precautions.

Under the law, employers should not dismiss or discipline employees who remove themselves from a situation at work where there is "serious and imminent" danger. But it should not be assumed that the workplace is more dangerous simply because of the strike.

If employees have any concerns about their own positions, or about safety in their workplaces more generally, they should be encouraged to talk to their managers. If they withdraw from work without the employer's permission, the law will not necessarily protect them from being penalised or, in certain circumstances, even dismissed.

ADDITIONAL FIRE SAFETY MEASURES FOR EMPLOYERS

Normal contingency planning is based on the presumption of early attendance by fully trained and equipped fire-fighting teams. This cannot be guaranteed for the duration of any action and accordingly there will be an increase in the level of risk from fire. Organisations are urged to check their preparedness and to review contingency arrangements. The main areas for this evaluation are as follows:-

• Ensure that business continuity and damage control plans are up to date:
• Check the effectiveness of existing fire precautions:
• Review arrangements for calling the emergency services in the event of fire:
• Lifts
• Workplace Fire Precautions
• Fire Warning and Detection
• Means of Escape in Case of Fire
• Means for Fighting Fire
• Maintenance and Testing
• Emergency Plans
• Fire Safety Checks at Shutdown

LINKS

Fire Industry Confederation at: www.the-fic.org.uk under 'news'
www.fire.org.uk provides a considerable amount of material on all fire issues.
The link General advice is offered at www.firekills.gov.uk.
The full text of this document can be obtained from:
http://www.safety.odpm.gov.uk/fire/firesafety/index.htm