

**Application Note: XRF**

# **Orbis Equipment Condition Monitoring**



advanced microanalysis solutions



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## **Introduction**

There are a variety of monitoring techniques available to the Condition Monitoring engineer each with its own particular benefit for given circumstances. To obtain the most comprehensive information about a possible wear situation, the combined results from more than one monitoring technique are often considered necessary.

Usually, the key issue is to obtain advance warning of any possible impending failure and confidently assess its likely consequences. An increasing amount of wear does not necessarily foretell that a disastrous failure is imminent. In certain circumstances, it is not just the knowledge of how much but **what** component(s) is wearing that the monitoring engineer needs in order to confidently diagnose any impending, especially “disastrous”, failure. Such timely prediction and its appropriate remedial action can prevent excessive costly repair &/or associated bills due to unscheduled shutdowns, secondary damage etc.

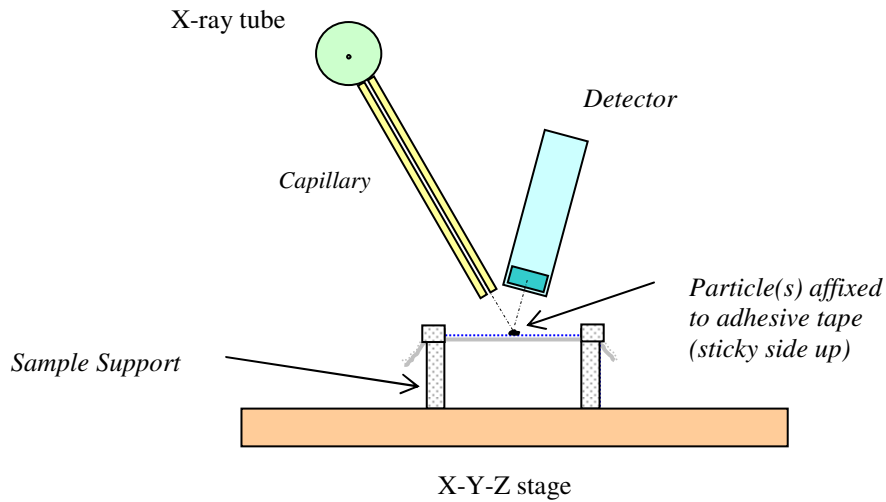
It is recognised that an early indication of a possible critical-wear situation is provided by the presence of larger wear-debris particles in lubrication oil lines of, for example, turbine engine gearbox & bearing assemblies. Such particles are collected on strategically located magnetic plugs during machine running time which are then periodically removed and the collected material investigated. Whilst any signs of wear warrant investigation, some may be quite benign and not require immediate attention. On the other hand, the debris may originate from a critical component such as a roller bearing and its raceway, which would warrant immediate remedial action.

The following discussion details how the versatile EDAX Orbis micro X-ray Fluorescence elemental analysis system may be used for the analysis/identification of wear debris particles. Whilst reference is limited to debris collected via magnetic plugs that collected via other means e.g. filters, may also be handled in a similar manner.

## **An overview of the Orbis EDXRF system**

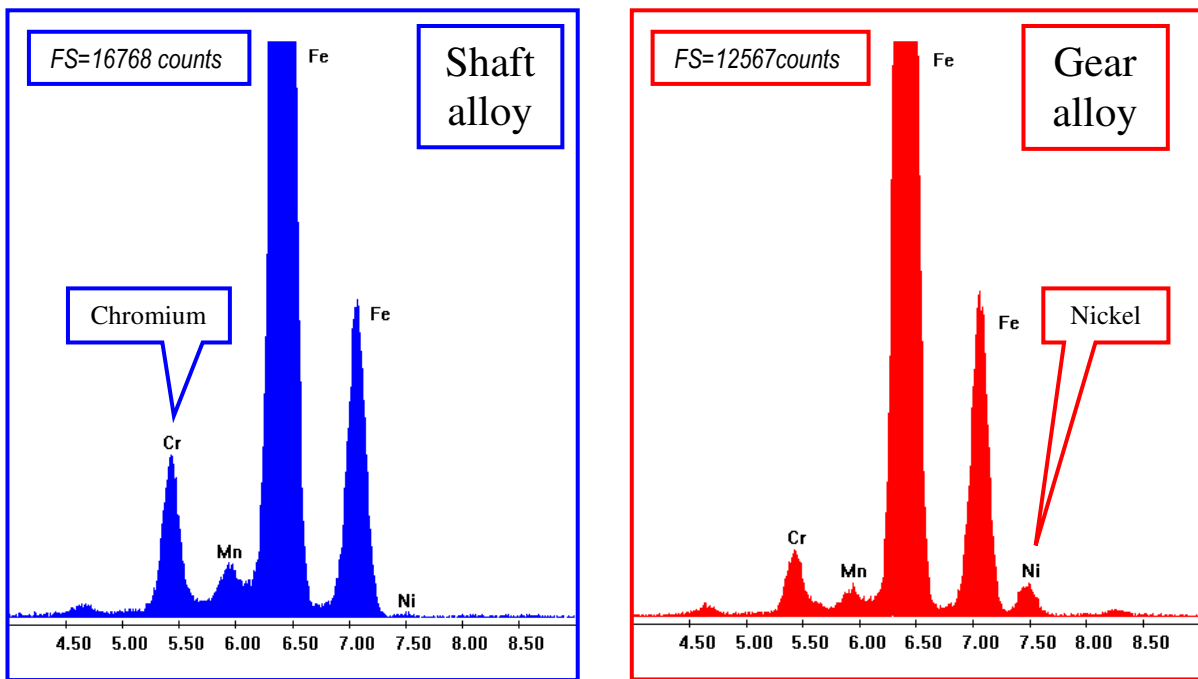
The Orbis is an Energy Dispersive X-ray Fluorescence (EDXRF) Spectrometry system that, by utilizing focusing capillary optics, provides a high-intensity small-spot analysis beam. Suitably supported samples are placed on the computer controlled XYZ specimen stage and, aided by the integral video cameras, quickly & easily brought to the requisite analysis co-ordinates (e.g. working distance etc). The standard system optics provides an analysis beam diameter of 300 μm into which debris particles of interest are rapidly located. Where the analysis of finer detail is required, alternative polycapillary focusing optics capable of producing extremely intense primary beams of ~50 μm diameter are also available. Samples are viewed and analyzed from above, an overview of the optics being given in **Figure 1**.

For any given sample or sample feature located within the analysis beam, an “energy” spectrum representative of its component elements together with information concerning their relative proportions is obtained simultaneously. Peak locations along this energy spectrum (x-axis) provide qualitative information concerning a sample’s “characteristic” X-ray spectra for its measurable component elements whilst their *intensities* (y-axis) provide *quantitative* information. The energy scale is usually expressed in units of kilo electron-volts (keV). The *shape* of the spectrum (which is a function of the “relative” intensities of its component elements) provides a “fingerprint” of its composition and is, to a first approximation, independent of sample size & shape.



**Figure 1.** Overview of optics & sample presentation

**Figure 2** illustrates the “fingerprint” properties of measured spectra. It shows the results obtained from different size pieces of shaft & gear “steel” alloys which have differing contents of, in particular, the alloying elements chromium (Cr) & nickel (Ni) in the iron (Fe) base. Direct comparisons between the intensities (& hence content) of the alloying elements in both samples is simplified when made relative (normalized) to that of the base element. Here the Fe intensities, whilst very different in absolute terms (FS  $\equiv$  Full Scale), are displayed to the same relative scale. To enhance the view of the alloying elements, the intensity scales have been expanded by a factor of  $\times 4$ . Clearly, the “shaft” alloy has a relatively higher Cr & lower Ni content compared to the same elements in the “gear” alloy.



**Figure 2.** EDXRF spectra of “shaft” & “gear” alloys illustrating how their relative shapes are a function of composition (see Table 1).

The main features of the EDXRF Spectrometry technique that make it especially suitable for Engine Health Monitoring applications include:

1. Covers a wide element range.  
Capable of simultaneous analysis for the elements Sodium (Na, Z=11) and above in the Periodic Table. Measured spectra “shape” are, to a first approximation, independent of sample size.
2. Vacuum or air measuring environment.  
It is not necessary to measure specimens under vacuum for the typical element range of interest with magnetic plug debris e.g. Vanadium (V, Z=23) and above in the Periodic Table.
3. The technique is non-destructive and no special sample preparation is necessary.  
The samples or their support do not have to be electrically conductive thus negating the need for special coating procedures. Samples may be archived and re-analyzed at any time.
4. A virtually instantaneous display of a sample’s spectrum is achieved. “Live” user/operator interaction enables qualitative analysis (for a total unknown) to be accomplished during data collection with major elements being identifiable within tens of seconds. Material identification by the direct comparison of the collecting spectrum overlaid on that of a reference may also be rapidly achieved.
5. Samples presented for analysis may be in any configuration e.g. solids, powders, particulates, thin films, liquids etc. It is possible to measure liquids in the Orbis system provided that the analyte line of interest does not require a vacuum path.

The Orbis system provides the opportunity to automate (batch analysis) the measurement of individually selected debris particles. It is first necessary to define their analysis X-Y-Z stage locations. Such stage locations represent the X-Y-Z motorized stage settings necessary to bring particles of interest into, or be covered by, the area of the primary beam. Typically this necessitates defining their X-Y co-ordinates with possibly small variations in their Z-axis settings dependent upon variations in particle sizes. This seemingly arduous task is very rapidly achieved using a “point & centre” utility within the video frame together with an “auto-focus” routine to position the particle under the X-ray beam. The X-Y-Z co-ordinates of the particle can then be saved for use in an automated analysis. Alternatively, the operator may prefer to take a more active role and investigate/analyze selected particles manually. Given the investigative (& potentially critical) nature of this type of analysis, this is often the preferred procedure.

### ***Magnetic Plug Debris***

Debris collected on magnetic plugs may contain material originating from any of the component parts contained within the mechanical assembly being monitored. Individual components (e.g. shaft, gear, roller or ball bearing, cage, raceway etc) are manufactured from “known-specification” alloys. In general, for any given mechanical assembly, the representative alloy compositions are usually sufficiently different to make them readily distinguishable from one another by, for example, the “shape” of their measured spectra. This is especially so in the case of bearing/raceway alloys compared to the remaining components. Once an alloy composition is determined, its component origin may be inferred.

Whilst a preliminary “eyeball” assessment of the debris actually adhering to a magnetic plug may be made, it is standard practice to transfer debris (after suitable degreasing procedures) onto ultra-transparent adhesive tape. Historically, this was then affixed to a white-paper card in order to facilitate a more critical examination using optical microscopy (via the adhesive tape) and for archiving purposes. Confident particle source identification by this method is, to say the least, extremely dependent upon the skill & experience of the relevant technician. Who could guarantee the outcome on a “bad” day! EDXRF methods, on the other hand, provide an easily implemented “objective” analysis technique.

It is preferable to prevent the occurrence of unwanted additional spectral lines in the measured EDXRF spectrum of any debris particle sample. Such additional lines could originate as a direct or indirect consequence of the interaction of the primary beam with, for example, the material upon which the debris is mounted/supported. This could occur when the primary beam was not completely intercepted by the specimen. Thus, the original tape with mounted debris is now affixed to an “easy peel” plastic-coated card. This facilitates removal of the tape from the card prior to presentation of the debris for analysis in the Orbis system. (The mounting card could conceivably contribute undesired spectral lines to the resultant spectrum.) In addition, particles are viewed/measured directly and not through the adhesive tape that is itself elementally “clean”. An overview of the sample presentation method is given in **Figure 1**.

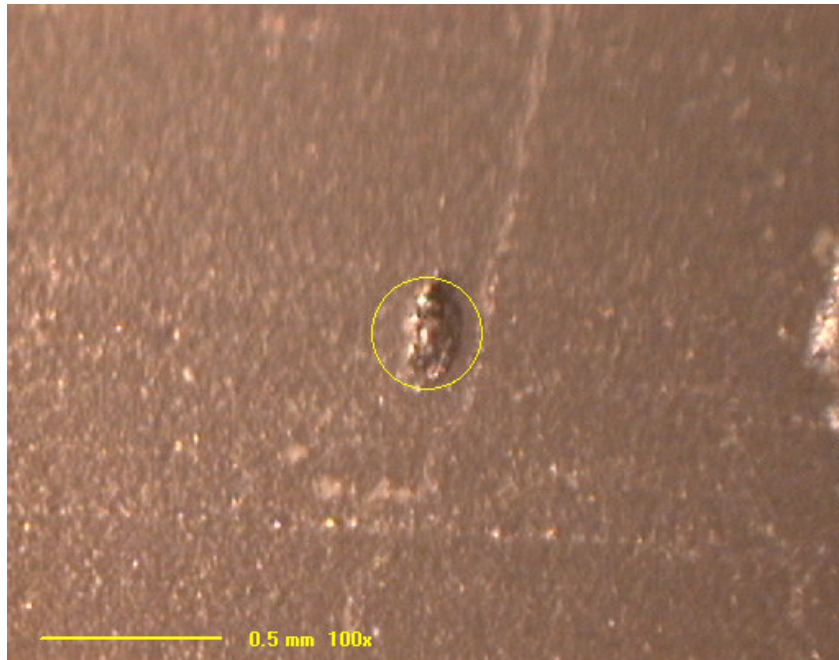
This sample collection/presentation method represents a minimal modification to the current industry practice for inspection/archiving of magnetic plug debris. Furthermore, no additional preparation is necessary prior to data collection.

### **Example of analysis capabilities**

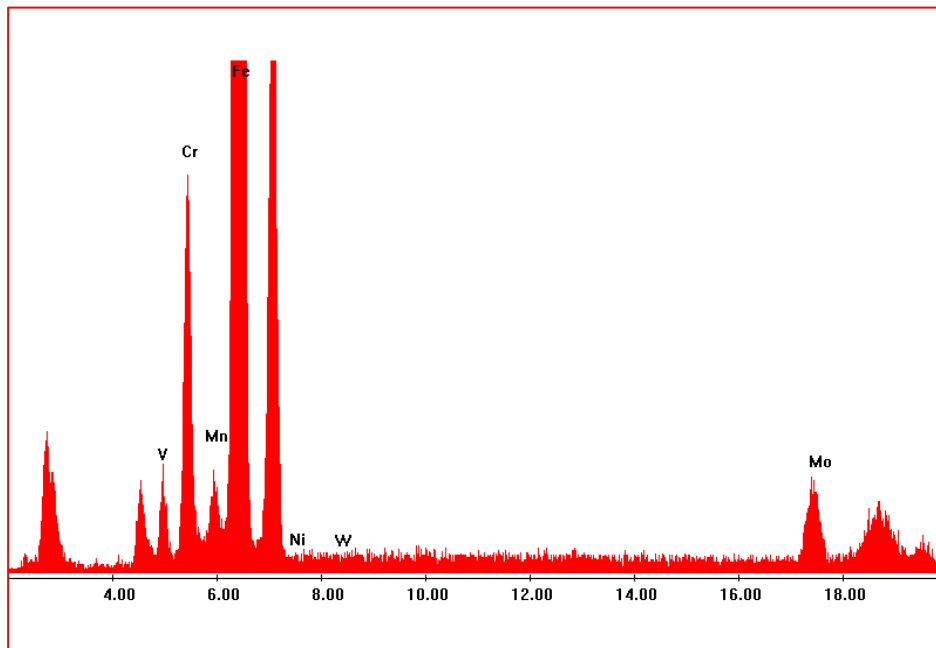
For the specific application of debris collected on magnetic plugs situated in aero (jet) engine oil lines, **Table 1** lists the average compositions of typical alloys used for a selection of components to be found in the monitored assemblies. The key elements that most readily provide detail to differentiate & identify the various alloys/components are Cr, (Fe), Ni, Mo, and W.

| Component type | alloy name | element % (Fe base)         |                             |                              |                               |                            |                            |                                |                             |
|----------------|------------|-----------------------------|-----------------------------|------------------------------|-------------------------------|----------------------------|----------------------------|--------------------------------|-----------------------------|
|                |            | <i>Si</i><br><i>silicon</i> | <i>V</i><br><i>vanadium</i> | <b>Cr</b><br><b>chromium</b> | <i>Mn</i><br><i>manganese</i> | <b>Ni</b><br><b>nickel</b> | <i>Cu</i><br><i>copper</i> | <b>Mo</b><br><b>molybdenum</b> | <b>W</b><br><b>tungsten</b> |
| bearing        | 18-4-1     | 0.25                        | 1.3                         | <b>4.5</b>                   | 0.2                           | -                          | -                          | <b>0.8</b>                     | <b>18.0</b>                 |
|                | RBD        | 0.3                         | -                           | <b>3.0</b>                   | 0.3                           | <b>0.7</b>                 | -                          | -                              | <b>10.0</b>                 |
|                | M50        | 0.2                         | 1.0                         | <b>4.1</b>                   | 0.25                          | <b>0.2</b>                 | 0.1                        | <b>4.3</b>                     | 0.2                         |
| cage           | 521        | 0.3                         | 0.3                         | <b>1.5</b>                   | 0.4                           | <b>0.4</b>                 | 0.2                        | -                              | -                           |
| gear           | S82        | 0.3                         | -                           | <b>1.3</b>                   | 0.5                           | <b>4.1</b>                 | -                          | <b>0.25</b>                    | -                           |
|                | S107       | 0.3                         | -                           | <b>1.0</b>                   | 0.5                           | <b>3.3</b>                 | -                          | <b>0.25</b>                    | -                           |
| seal           | jethete    | 0.3                         | 0.3                         | <b>12.0</b>                  | 0.7                           | <b>2.5</b>                 | -                          | <b>1.8</b>                     | -                           |
| shaft          | S106       | 0.25                        | -                           | <b>3.3</b>                   | 0.6                           | <b>0.3</b>                 | -                          | <b>0.6</b>                     | -                           |

**Table 1.** Example of typical alloy compositions employed in the manufacture of components whose wear-debris is collected on magnetic plugs.



**Figure 3.** Showing 300  $\mu\text{m}$  diameter analysis area and particle with approximate dimensions of 300 $\times$ 150  $\mu\text{m}$  mounted on adhesive tape.



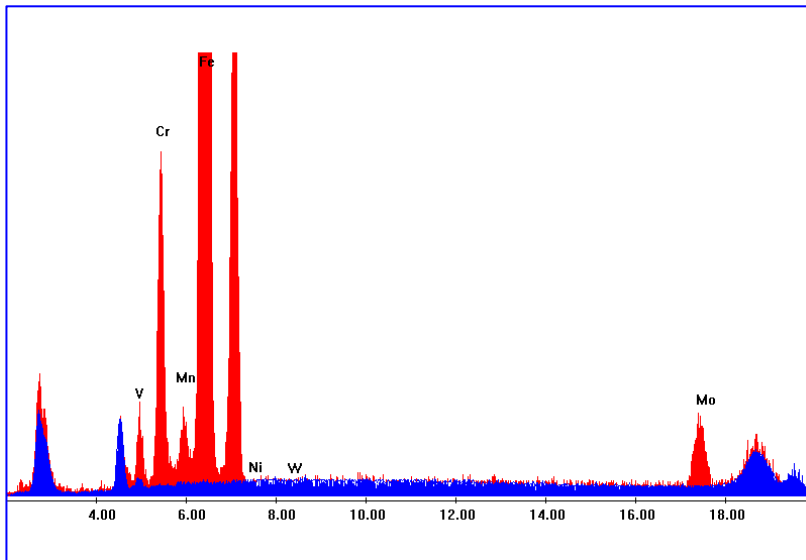
**Figure 4.** Showing spectra obtained from debris particle shown in Figure 3.

**Note:** The intensity scale (y-axis) has been scaled by a factor of 8 $\times$  in **Figure 4** and all subsequent spectral figures in order to enhance the visual interpretation of the lower concentration alloying elements (e.g. V, Cr, Ni, W & Mo) with respect to the dominant base element, Fe.

Automated MATCH procedures are available, which compare measured spectra of unknown debris particles with relevant reference data and suggest a “Best Match”. The procedure employed can be likened to the “manual” sequence illustrated in **Figures 3** through **7**.

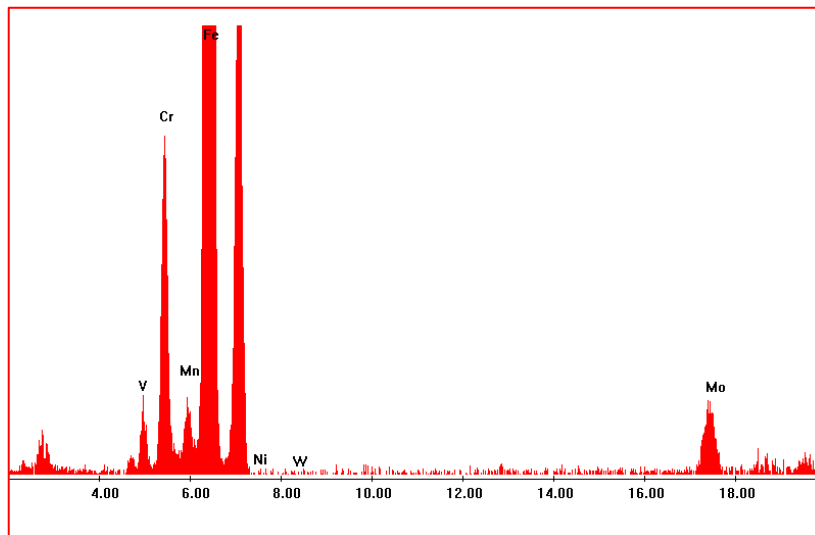
The spectrum for an unknown particle as, for example, shown in **Figure 3** is obtained after first locating it within the X-ray beam. In this instance the primary excitation area was 300  $\mu\text{m}$  in diameter but higher specific-intensity sources of 50  $\mu\text{m}$  diameter are also available. A measurement time of 100 secs was used and the resultant spectrum is given in **Figure 4**.

Since the debris particle did not completely intercept the primary beam, some “scatter” was obtained from the supporting tape. Thus, **Figure 4** shows the combined spectrum for the tape and the particle. [Such extraneous detail is minimized when using the 50  $\mu\text{m}$  primary beam diameter.] A “blank” spectrum from the tape is shown superimposed in **Figure 5**. By subtracting the “blank” spectrum, the spectrum attributable to the particle is obtained, as shown in **Figure 6**.



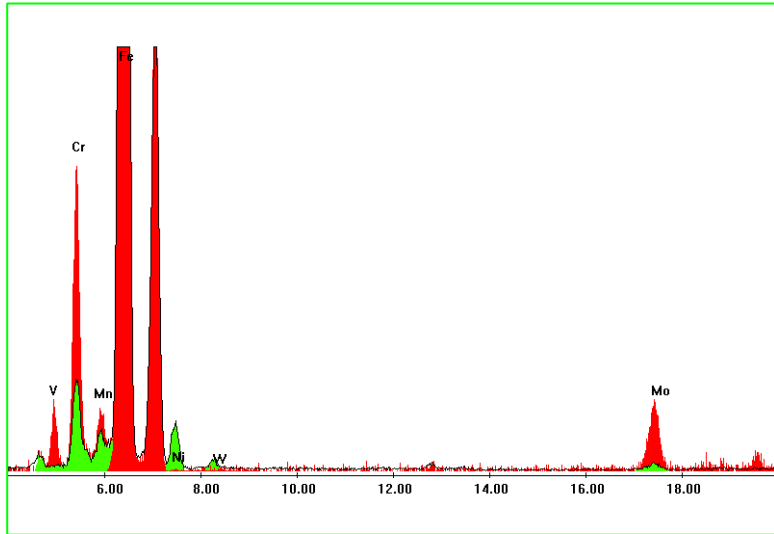
**Figure 5.**  
“Blank” spectrum (blue)  
superimposed on  
measured spectrum  
(red).

**Figure 6.**  
“Resultant”  
spectrum of the  
debris particle  
obtained after  
subtracting  
“blank” shown in  
Figure 5.

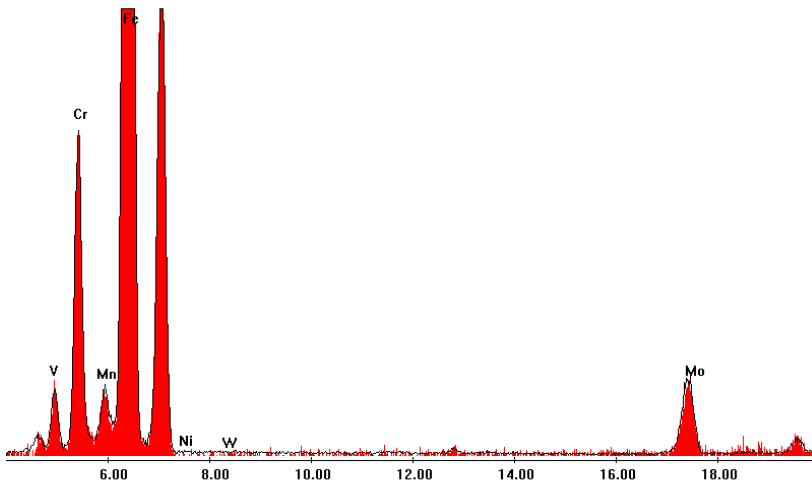


The “resultant” particle spectrum is compared to those within the database of the possible/known components (e.g. gears, bearings, shaft, cage, etc.) in the mechanical assembly being monitored. For example, the resultant spectrum obtained in **Figure 6** is shown compared to that of the gear alloy S82 in **Figure 7**. It is clear that in terms of the relative contents for V, Cr, Ni & Mo the spectra are quite dissimilar. Relative comparisons are possible because the intensities of the Fe peaks are normalized and shown on the same relative intensity scale. For example, it can be deduced that, to a first approximation, the Cr content for the unknown is about 3× that of the alloy S82.

**Figure 7.**  
The “resultant” debris spectrum (red) compared to that of the gear alloy S82 (green). The peaks for Fe are depicted using a common relative intensity scale. Thus the relative content of the alloying elements may be directly compared.



A good match for the unknown spectrum with that for the bearing alloy, M50, is shown in **Figure 8**. It can thus be confidently stated that the unknown wear debris originates from a component (e.g. raceway, roller or ball bearing) that is manufactured to the M50 specifications.



**Figure 8.**  
A good match between the shapes of the spectra for the unknown debris (red) and that for the reference M50 alloy (black line) is observed.

Note that the actual intensity scale maxima for the debris particle spectrum is 6800 counts whereas that of the M50 reference is 11000 counts. This again illustrates that it is the shape of the spectrum and not absolute intensity values that provide the requisite data needed for analysis.

An example of a typical Match Result Summary output for such an unknown debris measurement is shown in **Table 2**. It is always a good idea to visually check the computed result. The option to overlay the Matched Spectrum in compare mode, as shown in **Figure 8**, is available.

| <b>Sorted Sigma and Label [smallest sigma – best match]</b> |                        |
|---|------------------------|
| <i>sigma</i>  | <i>reference label</i> |
| 0.10  | M50                    |
| 0.21  | M50nil                 |
| 0.98  | 18-4-1                 |
| 1.76  | S82                    |
| 10.35   | jethete                |

**Table 2. Example of MATCH routine output**

## **Summary**

The capabilities of the EDAX Orbis micro-XRF analyzer for the simple & rapid identification of wear debris particles collected on magnetic plugs in aero (jet) engine oil scavenge lines has been discussed. However, this analysis is not limited to only this particular situation. The Orbis instrument and the methodology described in this note are applicable, in general, where analysis of metal particles and debris is needed - for example debris metals from other types of engines and metal particles deposited in a product by the processing equipment.

No special sample preparation procedures are necessary and the debris may be directly measured on the adhesive tape typically employed for their retention and visual inspection. Particles are rapidly brought into the appropriate analysis position via the computer controlled X-Y-Z stage and results obtained within a few minutes.

The results discussed here were obtained using 300 μm single capillary primary optics. Where particles smaller than ~150 μm need to be measured on a regular basis, the alternative polycapillary focusing optics system, which provides a very high intensity beam of 50 μm diameter, would be recommended. Such a system closely emulates the inorganic analysis capabilities normally attributable to SEM methods.