DETECTING BEARING AND GEAR FAILURES THROUGH AT-LINE WEAR DEBRIS ANALYSIS

Allison M. Toms
GasTOPS Inc
4900 Bayou Blvd, Suite 107
Pensacola, FL 32503
850-478-8512
atoms@gastopsusa.com

Abstract: To improve safety of flight operations, increase equipment availability and decrease ownership costs, it is imperative to monitor the condition of bearings and gears. To achieve full benefits, the utilization of technologies that can provide an early indication of potential failure is necessary, thus providing time for remediation and reduction of secondary damage. Traditionally, wear debris damage is detected through periodic sampled oil analysis that generates elemental indication of bearing or gear damage.

A viable and available alternative to sampled oil analysis is provided with an at-line wear debris alloy detector. The metallic particles captured by methods including chip collectors, filters, or oil sampling can be analyzed *at-line* utilizing x-ray fluorescence (XRF) technology and thus eliminate the need for laboratory metals analysis. Results achieved from individual particle identification provide a comprehensive analysis because the size of the particle and actual metal alloy can be identified.

This technology, investigated by the Air Force Research Laboratory (AFRL), has successfully been transitioned to a prototype product, tested and demonstrated at two USAF bases (Technology Readiness Level 6). In collaboration with GasTOPS, the Air Force initiated a project to provide a compact, automated, modular particle alloy identifier for at-line use. The prototype product offers a comprehensive first-line capability in a single, portable instrument that provides metallurgical analysis; pinpoints damaged internal components and can be used to determine system serviceability.

Keywords: Diagnostics, wear debris, alloy analysis, elemental analysis, at-line testing, x-ray fluorescence analysis, energy dispersive x-ray fluorescence analysis

Introduction: Determining the source of wear debris provides detailed information on the condition of critical, load-bearing, lubricated components and, as such, assists in the machinery health management decision making process. Traditionally, it has been necessary to collect oil samples, send these samples to a laboratory and await the elemental analysis of any wear debris. There is now an alternative. An at-line wear metal alloy identifier, designed by GasTOPS, has been demonstrated using proven energy dispersive x-ray fluorescence (EDXRF) technology.

The at-line device employs individual particle analysis utilizing a focused beam XRF to identify specific component damage by providing an exact alloy match. Particles can be obtained from a variety of sources: magnetic plugs, chip detectors, filter patches, and oil samples. The wear debris particles are sized and the specific alloy composition of each particle is identified. Maintainers of the machinery will be able to use this information to trace back to possible wear debris sources in the machinery and to estimate the severity and rate of progression of the failure.

The new at-line analyzer is based on XRF technology first investigated by the Air Force Research Laboratory. This paper presents an overview of the technology transition process, from AFRL to the current prototype device, and also presents a general description of the prototype and its field testing.

History of XRF in Bearing Diagnostics: The use of laboratory EDXRF spectrometers for wear debris analysis has increased over the past decade. Research into the use of XRF for at-line and in-line applications was pursued, in part through funding from AFRL. [1,2] In 2005, AFRL-PTRM initiated a collaborative R&D program with gas turbine and in-line sensor manufacturers to develop a capability that could be used in conjunction with an in-line oil debris monitor (ODM) for improved aircraft engine bearing fault detection and prognostics. This enhanced capability was based on the concept of an at-line debris analysis EDXRF system. AFRL felt that at-line debris analysis would substantiate and enhance ODM particle detection and isolate the source of debris. [3]

A subsequent cooperative research and development agreement (CRADA) followed in 2007 to refine ODM diagnostic algorithms and generate new prognostic algorithms for predicting the remaining life of rolling element bearings. Part of the project included characterizing the debris monitored by ODM as well as debris captured from other sources. The desired analysis tool was an at-flight-line XRF analysis device capable of determining material composition and size of the debris.

In 2001, GasTOPS had already successfully developed and fielded an XRF based analyzer using debris obtained from aircraft engine and gearbox oil filters. [4,5] This at-line automated filter debris analyzer is presently in operational use by the US Navy, Canadian Air Force and several Allied Forces. A second XRF-based product was also in development to accept oil debris from a number of sources (filter, magnetic chip collectors, or other debris capture devices) and to be capable of individual debris particle analysis. This new product development is based, in part, on technology developed by AFRL and the University of Dayton Research Institute (UDRI). The technology, successfully demonstrated in 2003, was part of the proof-of-concept project of a narrow-beam XRF analyzer that could analyze individual wear metal particles obtained from magnetic chip collectors and was capable of replacing the functionality of scanning electron microscope energy dispersive x-ray (SEM/EDX) analyzers. The device was based on a commercially available bench top EDXRF instrument and incorporated a computer-controlled sample translation table and proprietary software for particle recognition and automatic positioning of individual particles beneath the x-ray source. GasTOPS felt that the AFRL/UDRI concept offered the potential for a new product that could form the basis of a field deployable analyzer capable of individual wear debris particle analysis. In 2004, GasTOPS entered into a license agreement with the UDRI to commercialize the technology and commenced the development of this new product.

Fig. 1: Portable Wear Debris Analyzer

In 2008, GasTOPS was awarded a USAF Reduction in Total Ownership Costs (RTOC) project to produce an at-line XRF portable wear debris instrument. [6] The RTOC program of work was used to accelerate the product development and create a prototype analyzer that meets the specific requirements of the USAF for aircraft engine diagnostics and prognostics.

XRF and Alloy Identification: X-ray fluorescence spectroscopy is currently a widespread off-line application for metal and alloy identification. In the condition monitoring arena, it is used in laboratories as a stand-alone instrument, integrated into scanning electron microscopes (SEM) and in automated filter debris analyzers. At-line support of condition monitoring requires that the XRF device be co-located with the machine maintenance area and operated by ground support crew. XRF capability is currently utilized at-line for analyzing debris from component filters (broad-beam XRF, bulk analysis of debris) and with SEM/EDX for analyzing debris from chip detectors.

In XRF narrow beam spectroscopy, an x-ray source focuses an x-ray beam on a sample particle and a detector measures the energy levels and number of characteristic x-rays that are returned from the particles under evaluation. The energy levels of the characteristic x-rays correlate to specific elements within the sample particle, and the number of x-ray photons correlates to the quantity of each element that is present. This information on the elements and their relative quantities is compared to a pre-defined library of known alloy spectra. An alloy match is confirmed when numerous criteria are satisfied.

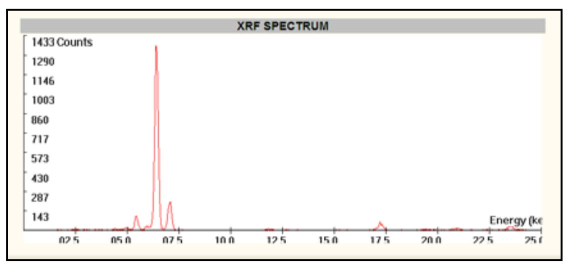

Fig. 2: EDXRF Spectrum of M50 Alloy

Prototype Debris Particle Analyzer: The debris analyzer is designed to analyze and identify metallic debris obtained from machinery lubrication systems in support of condition-based maintenance of the machinery. The instrument was designed to be compact and modular for ease of portability and to provide automated analysis for front-line use.

Fig. 3: Sample Sheet Placed in Analyzer

EDXRF analysis principles are used to determine the alloy of the metallic particles. To analyze the debris, an operator mounts multiple debris samples onto a sample holder, which is then inserted into the automated instrument. The operator labels the samples in the software and then presses “Analyze” on the unit. The instrument locates the particles, analyzes their size and shape and identifies the alloy for each particle. Individual particle identification is facilitated by the fact that particles are exposed to a narrow, collimated x-ray beam one particle at a time. The narrow beam allows analysis without interference from adjacent particles. Large particles are analyzed at more than one location so that the alloy matching analysis may determine whether the particle is of one composition or whether there are overlapping particles.

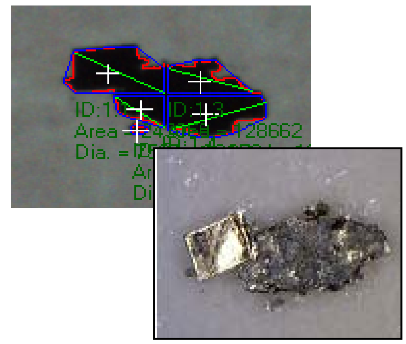

Fig. 4: Large Particle Analyzed in Several Locations

The system is also capable of providing warning levels based on the number of particles detected, their relative sizes, and alloy composition for the current sample and the trend in previous samples of the same serial numbered component. Limits provide an indication of the severity of wear and the remaining useable life of the component.

Field Testing: The prototype debris analyzer was field tested at two USAF bases. The purpose of the demonstration program was to evaluate the debris analyzer under operational conditions with respect to the following design objectives:

Performance and Function:

- Identify the alloy composition and size of particles. The primary objective is to be able to detect bearing steels to support proper diagnosis of aircraft engine condition based on specified criteria.
- Load and analyze 20 different samples in a single run.
- Analysis run time per particle should not exceed 30 seconds.

Physical:

- Provide above functions in a lightweight, field deployable unit.
- Operate on standard 110V, 60 Hz.

Fig. 5: Carrying Case

The debris analyzer was placed in operational environments with different deployment situations and evaluated by US Air Force personnel at each location.

The performance tests comprised the analysis of wear debris primarily from two sources:

- AFRL/RTZM bearing rig tests, collected by AFRL. This debris was primarily M50 NiL particles, but not exclusively.

- Debris collected by Army National Guard from failed Apache nose gearboxes. This debris was primarily M50 bearing particles as well as other debris from components found in gearboxes.

Conclusions: The RTOC project was focused on bringing the XRF analysis of individual particles to the field in a portable, lightweight, automated, modular instrument. The demonstration program showed that the prototype debris analyzer performed as designed and was able to:

- Identify the alloy composition and size of particles
- Load and analyze 20 different samples in a single run and analysis run time per particle did not exceed 30 seconds.
- Operate on standard 110V, 60 Hz.
- Provide this functionality in a lightweight, field deployable unit for front-line use.
- Achieve a Technology Readiness Level of 6.

The 2010 MFPT paper by Carl Byington, et. al., titled "Real-time Oil Quality and Metallic Debris Monitor for Gearbox Applications" describes a practical approach for this at-line application in conjunction with on-line wear debris and oil condition sensing.

References:

1. Whitlock, R.R., Humphrey, G.R., & Churchill, D. B., "Filter Debris Analysis by XRF Using Commercial Equipment Today", Lubr. Eng. 55, 10, pp 27-31 (1999).
2. Saba, C.S., & J. D. Wolf, "EDXRF for In-Line Condition Monitoring?", 2000 JOAP International Condition Monitoring Conference Proceedings, ed. G.R. Humphrey, et.al., pp 72-77 (2000)
3. Muir, D. & B. Howe, "In-line Oil Debris Monitor", Aerospace Engineering, Oct 1996
4. Toms, A.M., E. Jordan, and G. R. Humphrey, "*The Success of Filter Debris Analysis for J52 Engine Condition Based Maintenance*", Proc. 41st AIAA, AIAA-2005-4338, Tucson, AZ, July 2005.
5. Toms, A. M., & K. Cassidy, "*Filter Debris Analysis for Aircraft Engine and Gearbox Health Management* ", J. Fail Anal. Prev., Vol. 8, Iss 2, Apr. 2008.
6. Project # F33615-02-D-2299, "X-Ray Fluorescent Portable Lube System Debris Analyzer"