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Standard Guide for Filter Debris Analysis (FDA) Using Manual or Automated Processes[1]

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INTRODUCTION

Typically, main lubrication systems incorporate in-system filters to maintain an appropriate lubricant cleanliness level during operation. Since the lubrication filter element removes and retains a major portion of the solid contamination in the lubrication system, evaluation of the debris captured within the filter element aids in the determination of machine condition and root cause analysis (RCA).

The past decade has seen more widespread use of filter debris analysis (FDA) as a condition-monitoring tool to detect and analyze abnormal contaminant ingression into the lube system and predict lube system component wear. This is in part due to the increased use of finer filtration in machinery which results in a decrease of wear debris available for detection by traditional sampled oil analysis. The U. S. military and other militaries around the world as well as Original Equipment Manufacturers have adopted FDA techniques. Commercial in-service oil laboratories are also utilizing a wide range of FDA techniques, from manual to automated. It is necessary to provide a guide to improve analysis and comparison of data.

1. Scope

1.1 This guide pertains to removal and analysis techniques to extract debris captured by in-service lubricant and hydraulic filters and to analyze the debris removed.

1.2 This guide suggests techniques to remove, collect and analyze debris from filters in support of machinery health condition monitoring.

1.3 Debris removal techniques range from manual to automated.

1.4 Analysis techniques vary from visual, particle counting, microscopic, x-ray fluorescence (XRF), atomic emission spectroscopy (AES), and scanning electron microscopy energy dispersive x-rays (SEMEDX).

1.5 This guide is suitable for use with the following filter types: screw on, metal mesh, and removable diagnostic layer filters.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D5185 Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

D6595 Test Method for Determination of Wear Metals and Contaminants in Used Lubricating Oils or Used Hydraulic Fluids by Rotating Disc Electrode Atomic Emission Spectrometry

D7669 Guide for Practical Lubricant Condition Data Trend Analysis

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.96.06 on Practices and Techniques for Prediction and Determination of Microscopic Wear and Wear-related Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D7684 Guide for Microscopic Characterization of Particles from In-Service Lubricants
D7685 Practice for In-Line, Full Flow, Inductive Sensor for Ferromagnetic and Non-ferromagnetic Wear Debris Determination and Diagnostics for Aero-Derivative and Aircraft Gas Turbine Engine Bearings
D7690 Practice for Microscopic Characterization of Particles from In-Service Lubricants by Analytical Ferrography
D7720 Guide for Statistically Evaluating Measurand Alarm Limits when Using Oil Analysis to Monitor Equipment and Oil for Fitness and Contamination
D7898 Practice for Lubrication and Hydraulic Filter Debris Analysis (FDA) for Condition Monitoring of Machinery

2.2 *Other Documents:*
TTCP-AER-TP3-TR01-2010 Filter Debris Analysis Guide, July 2010, published by The Technical Cooperation Program (TTCP)[3]
SAE AIR1828 Guide to Oil System Monitoring in Aircraft Gas Turbine Engines[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *lubricant condition monitoring, n*—a field of technical activity in which selected physical parameters associated with an operating machine are periodically or continuously sensed, measured, and recorded for the interim purpose of reducing, analyzing, comparing, and displaying the data and information so obtained and for the ultimate purpose of using interim result to support decisions related to the operation and maintenance of the machine.

3.1.2 *machinery health, n*—a qualitative expression of the operational status of a machine sub-component, component, or entire machine, used to communicate maintenance and operational recommendations or requirements in order to continue operation, schedule maintenance, or take immediate maintenance action.

3.1.3 *prognostics, n*—a forecast of the condition or remaining usable life of a machine, fluid, or component part.

3.1.4 *remaining useful life, n*—a subjective estimate based upon observations, or average estimates of similar items, components, or systems, or a combination thereof, of the number of remaining time that an item, component, or system is estimated to be able to function in accordance with its intended purpose before replacement.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *filter debris analysis (FDA), n*—the analysis of debris specifically extracted from a system filter for the purpose of determining the health of the oil-wetted components within that system or the source of significant contaminants.

[3] Available from Technical Cooperation Program (TTCP), http://www.acq.osd.mil/ttcp/index.html.

[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

4. Summary of Guide

4.1 This guide provides practical guidance on filter debris analysis of in-service lubricant filters. Various techniques for debris removal, collection, and analysis are presented with their associated benefits and limitations.

5. Significance and Use

5.1 This guide is intended to provide machinery maintenance and monitoring personnel with a guideline for performing filter debris analysis as a means to determine machine condition. Correlating the filter contaminants to 'normal' and 'abnormal' lube system operation provides early indication of a contaminant or component wear related lube system problem. Analysis of the contaminant collected within the lube filter element provides a tool to identify the failure mode, its rate of progression, and the source of the contamination.

5.2 FDA differs from traditional oil analysis in that the filter is sampled instead of the fluid. Debris from the filter is removed for analysis. FDA is an effective means of monitoring equipment wear because the wear history is efficiently captured in the filter matrix. Typically, more than 95 % of all released metal particles larger than the filter pore size are captured in the filter (**1**).[5] In addition, other types of particulate contamination, including seal wear material and environmental contaminations are captured, which can also provide diagnostic information.

6. Interferences

6.1 *Time-on-Filter Information*—If the time-on-filter is not known, it is not possible to set limits for rate and severity of particulate generation.

6.2 *Analysis Techniques*—To compare filter debris from like equipment, the same filter extraction and analysis techniques must be utilized. Note some of the techniques in this guide are quite subjective such as visual analysis and manual extraction, which makes interpretation of results subjective.

6.3 *Operating Conditions*—Machine operational intensity impacts how quickly a component wears and how rapidly a fault progresses. Similar equipment operating under different conditions can generate different wear and be exposed to different contaminants. A relevant indicator of machine usage must be included in any trend and limit calculations. (See Guides D7669 and D7720.) The selected usage indicator must reflect actual machine usage, that is, life consumed for example, stop/start cycles, megawatt hours, hours of use, or fuel consumption.

6.4 *Maintenance Practices*—Care should be taken during removal of the filter to ensure that maintenance practices do not contaminate the filter.

7. Procedures

7.1 Typically, main lubrication systems incorporate in-system filters to maintain an appropriate lubricant cleanliness level during operation. The filter is incorporated either in the

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

pressure line after the main lubricant pump or on the scavenge line prior to the lubricant tank. Filter elements are full-flow and provide a coherent surface for capturing contamination in the lubricant. The porosity of the filtration medium can be optimized for filtration efficiency, subject to the desired filter element service life.

7.2 *Filter Media*—Several filter media types are presented that are suitable for FDA.

7.2.1 *Metal Mesh Filters*—These filters are common in engine and gearbox applications. Any of the debris extraction methods discussed in 7.3 can be utilized.

7.2.2 *Removable Diagnostic Layer*—Some lubrication filter elements are fabricated with a removable (pull-out) diagnostic layer, comprised of a porous medium layer. Fig. 1 depicts an engine lube filter element with a diagnostic layer. Typically, the porosity of the diagnostic layer allows for efficient retention of larger size debris (50+ µm) of diagnostic interest in engine lubrication systems (**2**). Since most porous media used in diagnostic layers are comprised of random fiber matrices, the 'diagnostic' layer exhibits lower, but significant, efficiencies in retaining contamination in the smaller size ranges. A primary advantage of the diagnostic layer is that it allows for a range of debris analysis from simple on-site visual or microscopic examination to more extensive laboratory analysis for determining the chemical elemental composition of the debris.

7.2.3 *Reusable Filters*—Some filters are reusable and should be treated as a serviceable part. The filter element manufacturer should be consulted to determine appropriate method to extract debris and to determine which tests are required to ensure integrity of the filter for reuse.

7.2.4 *Canister Filters (Screw-on Cartridge Filter)*—Cartridge filters are common in diesel applications. If manually cleaning a canister filter, the outer casing may need to be cut open to reveal the filter element for processing. Dedicated filter cutters are available that shear the canister open rather than sawing it, which minimizes any metallic contaminant ingress resulting from the opening process. Note there is the possibility of swarf contamination from the casing material during cutting.

7.3 *Debris Extraction Process*—There are several methods for extracting debris from filters. They range from manually removing large particles from the filter to automated filter back flushing.

7.3.1 *Manual*—Manual debris removal from filters has been practiced for decades. Different means for removing the debris range from manually extracting large debris from the filter to immersing the entire filter or sections of the filter in a solvent (such as polyol ester) compatible with the component oil system, separating the debris removed from the solvent by suction flask or simple gravity drain through cellulose media such as a coffee filter, and then analyzing the debris by visual, microscopic, or elemental methods. While manual techniques can be subjective and prone to interpretation anomalies, they can produce some limited information where procedures are strictly adhered to and where other techniques may not be practical.

7.3.2 *Ultrasonic Agitation*—Ultrasonic agitation improves the debris extraction from a filter element. The filter is submerged in a solvent and exposed to ultrasonic waves for a specified period of time. The solvent should be compatible with the component oil. Note some reusable filter elements cannot be cleaned using ultrasonic baths as damage to the element filter media may result. The debris is then separated from the solvent as in 7.3.1.

7.3.3 *Automated*—Particle recovery from filters can be performed automatically and efficiently using an automated filter-washing instrument. An automated system is available that automatically counts, sizes and discriminates between ferrous and non-ferrous particles, prepares a patch and provides associated elemental and alloy data utilizing its internal x-ray fluorescence (XRF) spectrometer. The automated FDA instrument provides a repeatable process by incorporating an automated filter back-washing fluid circuit utilizing a pulsed air/fluid mixture to remove up to 95 % of retained debris from the filter (**1**). As the filter is backwashed, debris particles flow through a wear debris sensor (Fig. 2) and are deposited on a membrane patch. See Figs. 3 and 4, and 7.4. The patch is then analyzed by an internal XRF spectrometer for elemental and alloy determination. The patch may also be analyzed by other means such as a microscopic analysis, SEM/EDXRF, or individual particle analysis. See 7.5. This automated technique, with no manual handling, provides a repeatable process for establishing limits and trends.

7.3.4 *Sectional Testing*—Sections of the filter may also be cut from the filter for extraction of debris. The assumption is that the debris is representative for the entire filter and an estimation of total debris is made. Any of the debris extraction techniques mentioned above can be used. See Practice D7898.

7.4 *Media for Debris Deposition*—Once the debris has been extracted from the filter, it must be captured on some media to

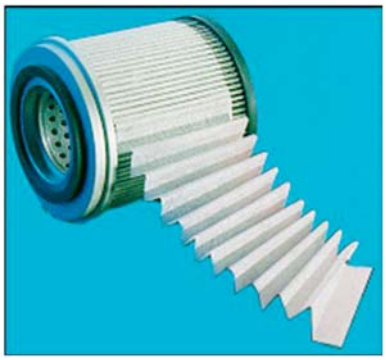

FIG. 1 Filter Element with Removable Diagnostic Layer

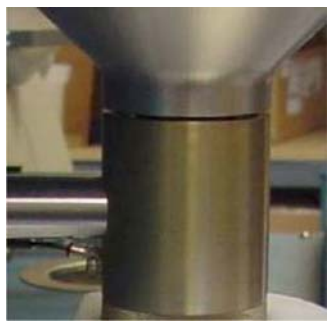

FIG. 2 Particles Counted and Sized

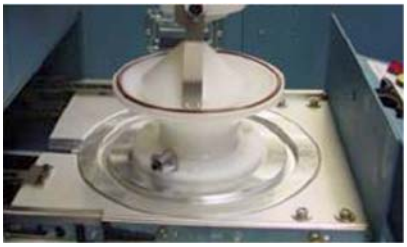

FIG. 3 Automated Patch Making Process

FIG. 4 Debris Patch

enable further analysis. Membrane patches are typically utilized. Membrane patches come in a variety of diameters (for example, 47 mm and 25 mm diameter), porosities (for example, 20 µm to 100 µm) and materials (for example, nylon and cellulose). The choice of membrane pore size is generally a compromise between particle isolation and prevention of clogging by finer contaminants such as oil degradation products and soot; and compatibility with fluids in the filters and those used for the extraction process.

7.5 *Debris Analysis Techniques*—Debris composition, size distribution, and morphology provide valuable information about the origin of the debris as well as potential fluid system component failure modes.

7.5.1 *Visual*—Debris extracted from filters can be visually inspected for a qualitative estimation of quantity of debris and size range of particles.

7.5.2 *Count, Weight, Mass, Type*—An automated filter debris extraction instrument has a built-in sensor that quantifies the debris as ferrous or non-ferrous, counts the particles, bins particles by size and type and provides relative mass of ferrous particles based on size range and quantity. (See Practice D7685.)

7.5.3 *Microscopic*—A microscopic evaluation provides particle morphology.

7.5.3.1 *Ferrography*—Ferrographic analysis provides particle features such as shape, color, edge detail, and surface features. (See Guide D7684 and Practice D7690.)

7.5.3.2 *Scanning Electron Microscopy (SEM)*—SEM provides higher magnification than ferrography and the use of instrument software provides automated particle analysis. By utilizing high resolution SEM and a computer generated "rotating cord" algorithm, SEM determines the number, size and nature of contaminant and wear debris particles. Further identification of the elemental chemical composition of the particulate can be determined using electron beam (see 7.5.4.3).

7.5.4 *Elemental and Alloy Composition*—The elemental composition of the debris aids in identifying the specific components wearing.

7.5.4.1 *Atomic Emission*—For atomic emission spectroscopy (Test Methods D5185 and D6595), the filter debris is suspended in a solvent, typically the oil used in the component. Since wear debris extracted from filters can easily be 100 to 1000+ µm, acid digestion is generally performed to overcome the inherent size limitations of the atomic emission.

(1) Acid Digestion—Elemental analysis by Inductively Coupled Plasma (ICP) can be used to evaluate debris for qualitative information of the type of inorganic material, that is, system components, wear debris, and external contamination. Samples are prepared by either *(1)* filtration onto a laboratory membrane or *(2)* concentrating a portion of the settled debris. The laboratory membrane and/or debris are then digested in acid to solubilize the debris. The elemental constituents of the debris are then measured by ICP. This method will not provide information regarding particle size of debris.

7.5.4.2 *X-ray Fluorescence (XRF) Spectroscopy*—For the bulk filter debris on a membrane patch, an XRF analysis technique called Fundamental Parameters **(3)** is performed and provides the elemental composition of the patch. Statistical analysis of composite results can be used to correlate various elemental profiles to known components and failure modes **(4)**. In addition, analysis of individual particles pulled from the filter or membrane patch is also possible using narrow beam XRF. This analysis typically utilizes spectral matching algorithms, which allow for specific alloy identification as well as elemental composition **(5)**.

7.5.4.3 *Scanning Electron Microscopy Energy Dispersive X-Ray (SEMEDX)*—SEMEDX determines elemental composition and individual particle alloy identification. However it can be very time consuming to determine the composition of every individual particle in a filter. Automated software aids in the characterization of complex matrices of particles distributed on a membrane patch. For instance, randomly selected particles are analyzed to infer global composition **(6)**. The technique employs a rule table to categorize components, which helps to further identify specific compounds. The classification rules may also allow for the trending of data from components of similar applications/systems.

8. Reporting

8.1 Unlike oil samples, the majority of wear debris released from a machine is captured in the filter. For filters from the same component and application with the same make and size of filter, the difference between debris removed from two filters is due to the time on filter and the wear mode. The time on filter can be taken into account (normalized). Thus the difference between filters is due to the wear modes and failures in progress. The size and number of particles can be trended (Guide D7669) over time indicating the rate of progression of the failure. The elemental or alloy composition analysis allows for identification of specific components wearing. Limits (Guide D7720) can be established for wear modes based on:

8.1.1 Number of particles,

8.1.2 Number of particles by size bins,

8.1.3 Number of particles by ferrous and non-ferrous,

8.1.4 Elemental content, and

8.1.5 Metallurgy of particles (alloys). **(4, 7, 8)**

8.2 For comparison purposes, reports should include details regarding time on filters, extraction technique, analysis technique(s), and so forth.

9. Keywords

9.1 condition monitoring; FDA; filter debris analysis; oil analysis; wear debris

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