A Standard for Filter Debris Analysis

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Abstract

The analysis of debris captured in lubrication system filter elements can provide high quality information about the health of a system and enable informed maintenance decisions. Traditionally the analysis of filter debris has been rudimentary and no standard was available to assist laboratories or machinery operators with the task. ASTM 7898-14 (Standard Guide for Lubrication and Hydraulic Filter Debris Analysis (FDA) for Condition Monitoring of Machinery) was released in early 2014 and seeks to provide a practical guide for both in-field and laboratory analysis. This paper will describe the genesis of the ASTM document and provide an overview of the contents.

Keywords: wear debris, filter, standard

Introduction

The detection of metallic wear debris entrained in lubricating oil is well documented as an effective machinery condition monitoring technique (1, 2). In this context wear debris is defined as metallic particles liberated from load-bearing components by means of a wear mode. Wear debris analysis forms an important part of most condition monitoring programs and is generally defined as the assessment of morphology, size, quantity and composition of wear debris generated by wear mechanisms in circulating fluid systems. The primary reason for assessing wear debris is to ascertain whether an incipient machinery failure has progressed passed an unacceptable stage.

Filter Debris Analysis

The purpose of Filter Debris Analysis (FDA) is to determine the health of oil-wetted machinery by analysing wear debris captured by the system filter. FDA is emerging as an important condition monitoring technique as fine filtration becomes more common and the associated reduction of metallic particulates makes traditional elemental analysis (e.g. spectrometric oil analysis) of the fluid less effective. System filters have an added advantage over traditional sample-based techniques in that they capture a high percentage of the total system debris (metallic, non-metallic and organic particulate contamination) within the size range useful for machinery condition monitoring. FDA can however be cumbersome to implement and the analysis of particle-rich samples can be difficult without appropriate guidance.

The Need for a Standard

The Technical Co-operation Program (TTCP) is a program for member nations to exchange information regarding defence science and technology activities. In 2010 the Propulsion and Power Systems Technical Panel within the Aerospace Systems Group published a guide for conducting FDA (3). This panel consisted of members from Australia, Canada, New Zealand and the United States who agreed that filter debris analysis was an emerging requirement and that a guide would assist with standardisation of methods. Whilst this enabled the member nations to conduct FDA in a unified manner, it became clear that a document that reached beyond military aviation applications would have merit.

One of the key motivations for development of the TTCP FDA document was the varied and disparate methods and guidance for FDA encountered in aircraft OEM maintenance manuals. Extension of the TTCP derived FDA document to wider industry was seen as highly desirable to allow for input from industry including civil and military aircraft OEMs. One of the objectives in this effort was to engage OEMs and operators to achieve robust standardised FDA that considers current generation systems being monitored. Furthermore a public standard allows for a platform to develop FDA methods appropriately as analysis techniques and systems evolve.

ASTM International[1] is a standards organisation providing a wide range of technical standards for general use. ASTM standards generally form the basis of commercial laboratory work and are the primary reference standards for lubricant and hydraulic fluid testing. The D02.96 sub-committee of ASTM focuses on In-Service Lubricant Testing and Condition Monitoring Services. In 2011 it was proposed to D02.96 that the TTCP document on FDA be transformed into an ASTM document. Over the ensuing two years the document was transformed into an appropriate format and further peer reviewed. In February 2014 D7898-14 was published as the Standard Practice for Lubrication and Hydraulic FDA for Condition Monitoring of Machinery (4).

Overview of the Standard

ASTM standard D7898 covers all aspects of extracting debris from filters, analysing the debris and reporting the results. It serves to provide the user with the recommended best practice based on feedback from developers of the document that include operators with extensive operational FDA experience, together with input from OEMs. Whilst the original TTCP document was aimed at aviation propulsion systems, the ASTM guide provides a generic document applicable to most types of machinery. An outline of the content of D7898 appears below:

- Definitions of wear debris and wear debris analysis specific to FDA;
- Intended use of FDA;
- Discussion of filter element types;
- Methods for debris extraction;
- Preparation of extracted debris for analysis;

[1] Formerly known as the American Society for Testing and Materials.

- Analysis of debris: assessment of quantity/size, composition, morphology; and
- Reporting of Results.

One of the issues with FDA has been identifying an overall assessment of the debris where many different types of particles are present. The Triplex plot (Figure 1) is included in the standard as a method of providing a simplified assessment of FDA results that can be quickly and intuitively interpreted. The plot can be used where no explicit guidance is provided by the machinery manufacturer for the assessment of filter debris. The plot consists of three concentric colour zones (green, yellow and red) representing the three index values (1, 2 and 3) used to assess each sector. The three sectors represent a size-count index, morphology index and a composition index. The plot functions as follows:

1. The analysis results are translated into indices (definition of index values are provided in the standard).
2. A vector is drawn from the origin of the plot out to the centre of the relevant sector at a radius corresponding to the allocated index.
3. If any **one** vector enters the red zone (index value of 3) then further investigation or maintenance is recommended.
4. If **two or more** vectors enter the red zone then maintenance action, a supplementary FDA or deeper investigation should be undertaken at the earliest opportunity.

In Figure 1 the debris observed in the analysis has morphology and composition that is of concern, however the quantity and size are not. This could indicate the early stages of a failure or residual debris from a previous event. As two vectors are in the red zone then further attention would be required for this sample.

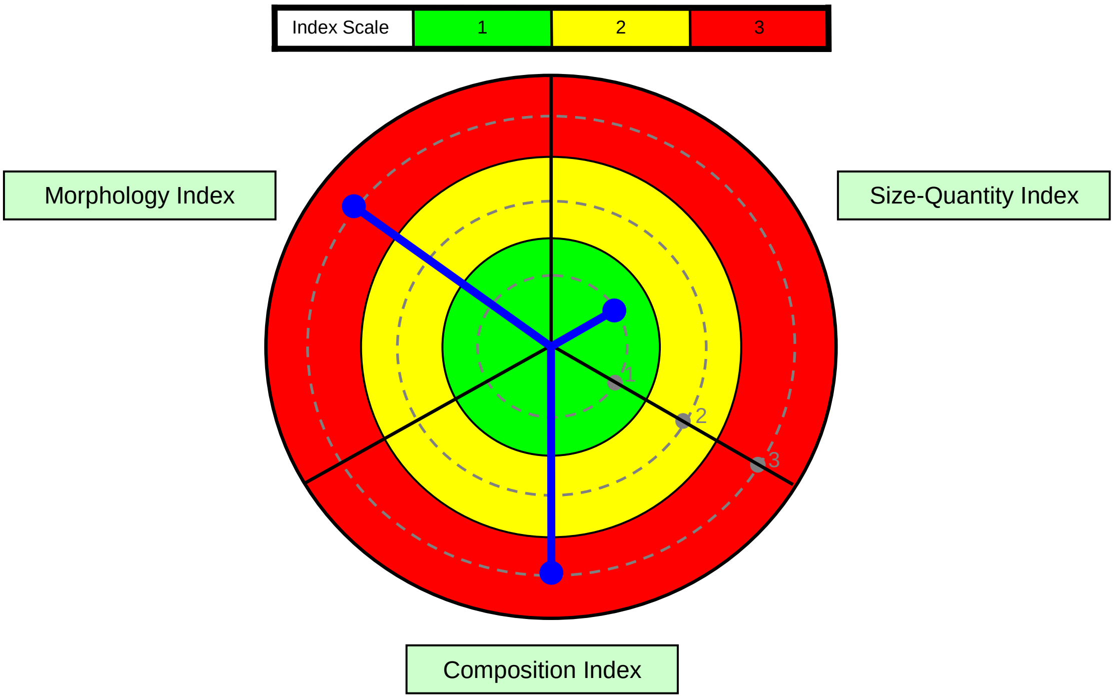

Fig. 1. Example of Triplex Plot

A method of manually extracting debris from a filter element and depositing it on a filter patch to enable further analysis either in the field of in a laboratory is described in detail. This element of the guide evolved primarily from the need to conduct FDA in the field or for deployed aircraft. The method is simple and highly effective for extracting the debris into a form that can be visually assessed in the field and then sent for detailed analysis should that be required. The inclusion of this manual method is considered to be very important to aircraft operators in the deployed environment. It enables extraction and therefore inspection of filter debris as opposed to only a cursory visual inspection of the exposed surfaces of filter pleats, which has been found to be inadequate to detect incipient defects robustly.

A recommended method of preparing extracted debris onto a nylon net ‘filter patch’ for analysis is provided, including recommended filter patch porosity that ensures samples avoid clogging while retaining critical debris for analysis. This is based from extensive practical analysis of filter debris from oil-wetted systems, particularly aircraft engines and gearboxes. Methods to separate ferrous debris on prepared filter patches are also described. This is a simple, yet essential step in the analysis of debris in order to separate out critical debris, from bearings, gears etc., that are invariably made from various alloy steels in legacy and current generation systems.

Guidance is provided on methods of analysis to assess the size/quantity, composition and morphology of debris particles. The exact analysis methodology an operator might use will be dependent on the availability of analysis equipment. Therefore, the guidance provided covers simple manual methods through to those that require specialist equipment, such as a scanning electron microscope.

Specific considerations are provided for each analysis method to ensure analysis is robust in the context of wear debris. For example there are definitions for the measurement of an individual particle by Feret’s diameter, a minimum list of elements to assess elemental composition against to ensure critical aeronautical alloys are identified, and minimum magnification requirements for assessment of debris morphology.

Assessment of the wear debris generation rate is emphasised in the document and is of critical importance in the assessment of filter debris. The time the filter has been in-service is discussed in the document and is recommended to be defined by the number of operating hours of the machine. The debris generation rate can only be determined where accurate installed time is known for the filter, which is why the document reinforces this point in the specification of a minimum set of data that should be supplied with the filter sample.

An important element often overlooked is the traceability requirements for wear debris, particularly when the analysis forms part of an incident or accident investigation. The ASTM standard provides guidance on how to ensure traceability from extraction of the debris through to archiving on completion of the analysis. It is essential to be able to identify the parent equipment responsible for the debris at any time from when it is extracted from the system until it is archived. This requires some clearly defined processes and the standard provides guidance on the important points to consider.

Finally, an appendix is included that shows images and describes the morphological features of wear debris. This concise library of images and the associated descriptors enables debris to be described consistently. Figure 2 is an example of an image from the document and shows the distinctive striations across the surface associated with a particle generated by adhesive wear.

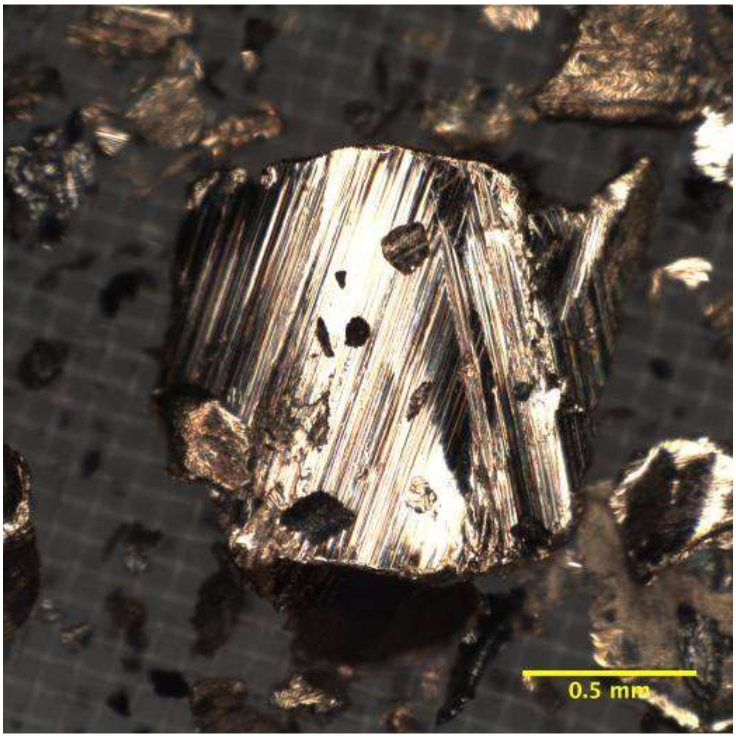

Figure 2: Example of adhesive wear debris from morphology library showing characteristic striations across the surface

Future Work

A companion document is being considered that would cover generic analysis of wear debris retrieved from magnetic chip detectors /collectors or sump drains. This document would cover topics such as the extraction and transport of debris, analysis (including size, count, shape and morphology aligned with the current FDA standard) and reporting requirements. A further section would define the requirements for inferring the significance of the bulk debris based on an analysis of a representative sample. Similarly a section is planned that would define the requirements for inferring the composition distribution of a population based on a representative sample.

Conclusion

A new standard has been developed for the analysis of wear debris extracted from hydraulic and lubrication system filters. This work was initiated by TTCP and the original report was then converted to an ASTM International Standard. Whilst the original TTCP document was developed primarily for aviation applications, the ASTM standard that evolved from it is generic and applies to most machinery types. This standard contains useful information to ensure the extraction, analysis and reporting of filter debris can be done consistently and enable comparison of results. The conversion to a peer reviewed standard that is administered by a respected international organisation provides both military and non-military users with access to the information. It is hoped that the existence of this standard will enable equipment OEMs to provide consistent and meaningful guidance to maintenance staff regarding serviceability assessments involving wear debris, particularly in the aviation sector. Furthermore it provides a platform from which to develop and promulgate best practice for FDA into the future.

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