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FilterCHECK 300/EDXRF AUTOMATED FILTER DEBRIS ANALYSIS

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14. ABSTRACT

The FilterCHECK 300/EDXRF instrument is an improvement over its predecessor – PRAM beta prototype instrument. The FilterCHECK 300/EDXRF instrument is manufactured by GasTOPS, Ltd., Ottawa, Canada. The FilterCHECK 300/EDXRF instrument combines EDXRF analysis technology with a GasTOPS MetalScan particle counter; with the entire instrument controlled by fully automated software to produce a powerful prognostic/diagnostic tool that can detect the onset of component failure much earlier than traditional methods. Data from the FilterCHECK 300/EDXRF instrument combined with a filter debris analysis (FDA) program will greatly enhance an organization's condition based maintenance (CBM) program.

15. SUBJECT TERMS

FilterCheck 300/EDXRF, filter debris analysis, condition based maintenance.

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FilterCHECK 300/EDXRF Instrument
Automated Filter Debris Analysis

Executive Summary: The FilterCHECK 300/energy dispersive x-ray fluorescence (EDXRF) instrument does perform as stated by GasTOPS, Ltd. The FilterCHECK 300/EDXRF is designed to detect abnormal wear of machinery components by analyzing the wear particulates (debris) washed from an expended filter element. The FilterCHECK 300/EDXRFis an improvement over its predecessor – PRAM beta prototype. The FilterCHECK 300/EDXRFinstrument is manufactured by GasTOPS, Ltd., Ottawa, Canada. The FilterCHECK 300/EDXRF instrument combines EDXRF analysis technology with a GasTOPS MetalScan particle counter; with the entire instrument controlled by fully automated software to produce a powerful prognostic/diagnostic tool that can detect the onset of component failure much earlier than traditional methods.

The instrument extracts a sample of particulates from in-line filter elements and deposits the particulates on a 20 micron filter substrate. A sample of particulates extracted from the filter element is then automatically analyzed by EDXRF and the elements that compose the particulates are reported as percentages. The number and size of metal particles in the filter are analyzed using a MetalSCAN debris sensor, while the elemental composition of the debris is analyzed using an EDXRF sensor. The Joint Oil Analysis Program Technical Support Center (JOAP-TSC) developed a method -- filter debris analysis (FDA) that will interpret the percentages of each element reported by EDXRF analysis and relate the percentages to abnormal wear and point to engine components that are exhibiting abnormal wear.[1] The data gathered by the unit can be downloaded via a serial cable to an external database system for storage of sample results, or the results can be read directly from the FilterCHECKs integrated displays. The unit also produces a sample patch of the filter debris that can be sent to an off-site lab for more detailed analysis.

The FilterCHECK 300/EDXRF is designed to be used at the on-site or off-site level of a Conditioned Based Maintenance (CBM) or Integrated Health Maintenance (IHM) Program. The instrument provides information directly to maintainers that was previously only available using rudimentary on-site analyses or sophisticated off-site laboratory analysis. This allows maintainers to make immediate maintainence decisions before potential problems result in costly failures to the equipment.[2]

The FilterCHECK 300/EDXRF will greatly enhance any condition based maintenance (CBM) program that is based upon analyzing alloy fragments removed from magnetic chip detectors (MCD). The instrument provides a capability to reduce unscheduled maintenance by detecting initial indicators of upcoming failures modes, such as the shedding of sacrificial coatings like silver.

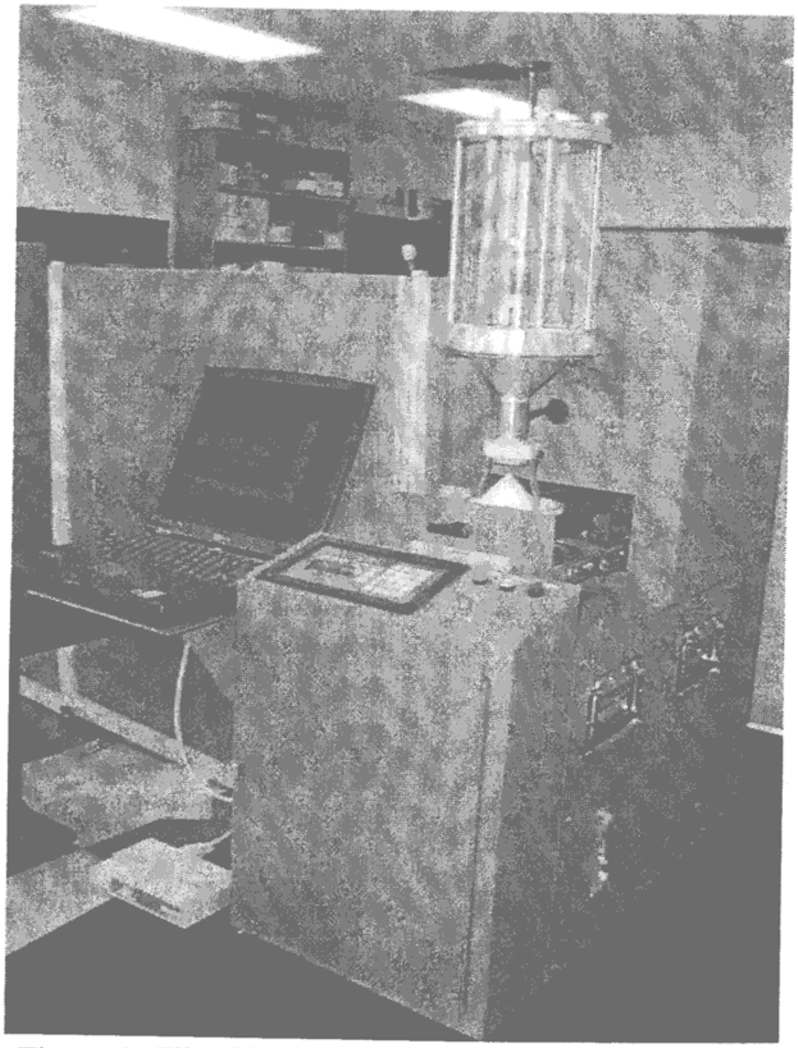

Figure 1. FilterCheck 300/EDXRF with laptop computer.

Background: GasTOPS, Ltd. participated in the design and manufacture of 6 beta prototype filter debris analysis (FDA) instruments for the Joint Oil Analysis Program Technical Support Center (JOAP-TSC) under an Air Force (AF) Productivity, Reliability, Availability, Maintainability (PRAM) project. J52P408 (J52) engines were suffering from what appeared to be sudden, catastrophic failures that had resulted in the loss of aircraft. The root cause of the failure was lack of lubrication in the 4 ½ bearing area that caused the 4 ½ bearing cage to fracture. The analysis of oil samples by rotrode emission spectroscopy did not indicate a catastrophic bearing failure mode was evolving. FDA-EDXRF was one of the techniques employed to try to discover the onset of 4 ½ bearing failure. An FDA-EDXRF profile of the J52 engine was developed in about 3 weeks. Initially, particulates obtained from J52 filters where FDA indicated that abnormal amounts of bearing wear was present in the engine were sent to Pratt & Whitney Aerospace laboratory to be analyzed by scanning electron microscopy (SEM). The SEM results confirmed the presence of M-50 alloy or bearing wear. Subsequent teardowns of a portion of the engines having abnormal bearing wear indicated by FDA had fractured 4 ½ bearing cages. The beta prototype instruments were 98% effective in detecting 4 ½ bearing failures in the J52 engines.[3] The tremendous success rate that filter debris analysis (FDA) demonstrated prompted the US Navy to purchase the next generation FDA instruments from GasTOPS, Ltd. -- the FilterCHECK 300/EDXRF instrument.

FilterCHECK 300/EDXRF Instrument: The manufacturer GasTOPS, Ltd. markets this instrument as a prognostic/proactive maintenance tool. The FilterCHECK 300/EDXRF instrument automatically removes particulates from in-line oil filters, counts and sizes ferrous and nonferrous particulates with MetalScan, deposit particulates on a nylon filter substrate (patch), analyze the particulates on the nylon filter patch by EDXRF with software able to capture and interpret the data. The filter cleaning chamber is versatile and can handle a wide variety of sizes and configurations of filter elements. The FilterCHECK 300/EDXRF contains many improvements over its predecessor the PRAM Beta prototypes. Examples follow:

1. Larger capacity filter wash chamber.
2. Solid state circuitry.
3. Sample platform stability.
4. X-ray control.
5. Enclosed solvent reservoir.
6. Quick disconnects for plumbing and circuitry.
7. Simpler troubleshooting.
8. Electromagnetic interference susceptibility hardened for shipboard use.
9. Environmentally hardened.
10. Reliability.

FilterCHECK 300/EDXRF Instrument Functions: A filter element is placed inside the filter wash chamber with appropriate fittings to allow cleaning of the filter element. Particulates are removed automatically from an in-line oil filter. A computer onboard the instrument is programmed with all of the sequences of events that will extract particulates from an oil filter element. Each event is timed, so every filter element is cleaned in exactly the same manner.

The filter element is cleaned by two different processes – one process produces a sample of the filter element debris for EDXRF analysis. The other process cleans the filter element for an extended period of time. The only limitation is the size of the extraction chamber for filter elements. Currently, the chamber can accommodate filters up to 9 1/2 inches in height and 5 3/16 inches in diameter. However, larger chambers can be manufactured and fitted to the instrument.

The process that produces a sample for EDXRF analysis is a sequence of events with the occurrence of each event controlled by a specified period of time. A sample assembly consisting of a funnel, filter support screen and a nylon filter patch of a specific pore size are used to capture the solvent and particles as they exit the MetalScan particle counter. The result is the production of a sample of particulates from the filter element that are randomly distributed on the surface of a nylon patch of a specific pore size. The particulates extracted from the filter element are representative of the wear modes that the engine has seen during the filter element's life. Each filter element has particulates extracted from it in exactly the same manner. Once the sample of particulates is produced, the sample will move into another area of the instrument to be analyzed by EDXRF.

The EDXRF system consists of a miniature x-ray tube paired with a silicon pin detector. The power to the x-ray tube is controlled from the computer onboard the FDA instrument. Each exterior panel that can be removed from the main frame of the instrument has an interlock associated with it. The tray that moves the EDXRF sample into and out of the x-ray chamber also engages an interlock when the sample is in the x-ray chamber. Another interlock is that the vacuum must be attained. All of these interlocks must be satisfied before the x-ray tube can be energized. Once the x-ray tube is activated, no radiation will be detected outside the chamber. These safety features are designed to prevent operators or maintenance personnel from accidentally energizing the x-ray and exposing themselves to x-rays.

Particles that are liberated from a filter element are counted and sized by a MetalScan particle counter. The MetalScan particle counter detects ferrous (magnetic) and nonferrous (nonmagnetic) particles in three different particle size ranges. During the production of the sample for EDXRF analysis, particles are counted. While the EDXRF analysis of the sample is occurring, a filter element wash cycle is activated that continuously cleans the filter element and reports the particle counts. Ferrous particles are detected in the following bin sizes:
100-200 microns
200-500 microns and
500 microns plus
Nonferrous particles are detected in the following bin sizes:
400-500 microns
500-900 microns and
900 microns plus
All of these types and sizes of particles are detected automatically as the particles are liberated from the filter element. [2]

EDXRF: Once the sample is produced, the sample platform is moved into the area of the instrument where EDXRF analysis can commence. A button is pushed to begin the x-ray cycle. A platform is raised to push the sample funnel against the roof of the x-ray chamber and a vacuum is initiated. A vacuum is necessary to detect the fluorescent x-rays from light elements, e.g., magnesium (Mg), aluminum (Al) and silicon (Si). Once the desired vacuum condition is obtained, the x-ray tube is manually activated through the onboard computer.

A laptop computer is interfaced to the FilterCHECK 300/EDXRF. Data from the EDXRF analysis of the particulates and MetalScan particle counts are transmitted to the laptop computer. The x-ray software can be configured to detect and analyze 30 elements simultaneously. Software for the x-ray system and the MetalScan automatically interprets the EDXRF and MetalScan data and displays the results. The results from both analyses can then printed out or sent to other software.

EDXRF is the type of x-ray measurement used in the FilterCHECK 300/EDXRF. The sample (particulates) absorbs some of the x-rays emitted from the x-ray tube. Elements in the sample emit x-rays, in all directions, in a process known as fluorescence. Some of the x-rays are absorbed by the silicon pin detector. The absorbed x-rays produce pulses with voltages proportional to the x-ray energies that were absorbed. The electronic separation and counting of the pulses according to their heights yields a photon energy spectrum, a process known as energy dispersion. [4] This spectrum contains the information identifying which elements are present in the sample and the quantity of each element in the sample.

The debris from oil filters is composed of metal particles from many different alloys. The percentage of a given element in the sample produced by the FilterCHECK 300/EDXRF is a mixture of alloys and does not have the same meaning as the percentages in a single alloy. The elemental analysis of wear particulates by EDXRF, for the purposes of condition monitoring, can be carried out quite effectively by a statistical analysis of the percentages alone without addressing the theoretically complicated issue of concentration for these particulates.

The x-ray spectral data is analyzed by an approach known as thin film analysis. Thin film analysis applies where all of the atoms that compose the film transmit essentially all the fluorescent x-rays. The samples of wear particulates produced by the FilterCHECK 300 are essentially a mixture of infinitely thin films and intermediate thickness films. Such thickness effects, when discussed in terms of particulate samples, are often referred to as particle size effects. Fortunately, the effect of particle size is to increase the measurement sensitivity for smaller particles and is accounted for in the statistical analysis of the data.

Intermediate thickness films, large particles and bulk samples of alloys can exhibit matrix effects, where the fluorescent intensity radiated, per atom of a given element, depends upon the alloy composition. This complication is handled by Fundamental Parameters (FP) calculation. The FP calculation produces the matrix correction factors (alphas) and the estimate of sample thickness. Once the sample thickness is found, the alphas are calculated and the percentage of each element being analyzed for is reported. The above explanation is a simplification of the EDXRF process and the derivation of element percentages from a sample of particulates, but is sufficient for a basic understanding of the relevant processes. [5]

FDA. FDA is a technique and technology conceived by the Joint Oil Analysis Program Technical Support Program (JOAP-TSC). FDA is based upon the particulates captured by the in-line filter element during the filter element's life. The filter element removes particulates resulting from wear from the entire volume of lubricant every time the fluid cycles through the system. The filter element becomes a repository of the wear that the system has endured during the lifetime of the filter element.

The FilterCHECK model 300 was developed and fielded predicated on the PRAM Beta prototypes ability to detect bearing failure in the USN J52P408 engine. The discussion of FDA will be limited to this experience.

The J52P408 jet engine was experiencing catastrophic failures that had resulted in the loss of aircraft and crew. The root cause was identified as the failure of the 4 ½ bearing assembly. An FDA profile was established based upon detecting M-50 alloy (bearing material). M-50 alloy is mainly composed of Fe with Cr, Mo and V composing minor percentages of M-50 alloy. Fe and Cr appear in a lot of alloys that compose jet engines, so they would not be definitive markers for M-50 alloy. The combination of Mo and V appear in only one alloy in this engine, M-50 alloy, so Mo and V were defined as the markers for M-50 alloy.

Filter elements from J52P408 engines were removed from all the engines in operation and an FDA profile was established within 3 weeks. A set of 19 EDXRF element and MetalScan particle count guidelines were developed that would determine the maximum percentages of V and Mo and other elements that should be in the system. The process used to develop these element guidelines is listed below:

1. Arrange the EDXRF percentages of each element in columns.
2. Find the mean and standard deviation for each element.
3. Establish the maximum and minimum value for each element.
    a. The maximum value for each element was established by taking 3 times the standard deviation calculated for the element plus the mean for the element.
    b. The minimum value was established by subtracting 3 times the standard deviation calculated for the element from the mean for each element.
    c. Any value falling outside of the minimum-maximum range are outliers.
    d. Recalculate the mean and standard deviation for each element, but do not include the outliers.
    e. Establish the maximum percentages of Mo and V allowed in the system; the mean plus one standard deviation. [6]

If the percentages of Mo and V exceed the calculated limits then there is too much M-50 alloy in the system and FDA is indicating abnormal bearing wear. Removal of the engine is warranted and the 4 ½ bearing assembly needs to be visually observed for defects. Another valuable indication that FDA yielded was detecting the presence of Ag. Ag is used to plate the bearing assemblies in the J52P408 engine. In FDA analysis, Ag is viewed as a precursor to the 4 ½ bearing failure. The indication of Ag automatically reduces the amount of time the filter spends in an engine to half of its normal time. Other indications from FDA are as follows:

1. Si - blasting media.
2. Al & Cu – oil pump.
3. Fe - #1 bearing
4. Cd – plating.

5. Mg – gearbox housing. [7]

Overhauled J52P408 engines must pass FDA prior to being issued to the field. FDA has been reported to be 98% effective in finding 4 ½ bearing failures. The original values for elements detected by FDA have been modified by the USN J52 engineers to reflect the performance the J52 engineers want from the J52P408 engine.

Software Update. To obtain accurate results from x-ray analysis, the alignment of the x-ray energy spectrum must be done prior to the analysis of samples. The alignment of the x-ray energy spectrum is accomplished by EDXRF analysis of a zinc telluride (ZnTe) thin film standard. The spectrum produced from an EDXRF analysis will have in it the Zn K-alpha and the Te L-alpha peaks. These two peaks, Zn K-alpha and Te L-alpha appear at specific x-ray energies, 8.631 and 3.769 Killielectron Volts (KeV) respectively.[8] Spectrum alignment is accomplished through several software steps and visual observation that the Zn and Te peaks are truly in alignment after the alignment procedure was accomplished. Alignment or standardization of the energy scale is absolutely essential to obtain accurate results from the analysis of samples. If the element peaks are not properly aligned on the energy scale, the software will not correctly identify elements, the software will derive the wrong intensity for elements and report erroneous percentages for each element. This is why it is so important to correctly align the energy scale and continue to monitor that alignment throughout the analysis of samples.

An "Automatic Calibration" (Autocal) function was added to the software to eliminate the subjective nature, e.g., visual observation of the alignment of the Zn and Te peaks, of the ZnTe standardization of the x-ray energy scale. The Autocal function will automatically align the Zn and Te peaks with the x-ray energy scale without operator intervention, report the calibration factors, update the detector resolution factor and request another analysis of the ZnTe thin film before the software accepts the initial values of the aforementioned parameters. After the second analysis, the software automatically checks that the Zn and Te peaks are aligned, saves the values for the calibration factors and saves the value for the detector resolution. However, the Autocal function does not release the operator from the responsibility of observing that the Zn and Te peak energies are aligned with the energy scale.

Another feature of the software update was for the software to detect that a spectrum from a sample was aligned with respect to the Iron (Fe) K-alpha peak. If the Fe K-alpha peak is aligned there are no adjustments to the spectrum. However, if the Fe K-alpha peak is not aligned with respect to the energy scale then the software aligns the spectrum prior to the derivation of element intensities. This function is not to be activated during the Autocal process because spectrum alignment is based upon Zn and Te x-ray energies not Fe. The updated software also allows for the analysis of samples with high deadtimes. High deadtime can occur during EDXRF analysis when a sample is emitting large amounts of x-rays -- essentially overwhelming the detector with signal. When the deadtime for a sample exceeds 30%, a phenomenon known as spectral shift can occur which essentially causes the element peaks not to appear at their respective x-ray energies (shift). This phenomenon will cause the software to misidentify element peaks and report

erroneous element percentage values. Prior to updating the x-ray software, an analyst had to split a sample whose deadtime exceeded 30% -- to reduce the deadtime. With the updated software, the deadtime can be up to 50% and the software will correctly align the x-ray spectrum so that the percentages reported for the elements are accurate.
The addition of this software function will increase the accuracy of reporting EDXRF results. The software will decrease labor caused by having to split samples due to deadtimes exceeding 30%. The software is designed to aid field personnel -- not to totally relieve them of the responsibility for observing that the software did successfully align the element peaks to the x-ray energy scale.

Transportation. The x-ray system of the FilterCHECK 300/EDXRF is sensitive to abusive handling during shipment. A shipping container for the instrument was designed by GasTOPS, Ltd. that addressed this problem. The shipping container is also designed for transporting the FDA instrument and to accommodate two additional carrying cases. One of the cases is for the laptop computer plus accessories and another case is for consumables associated with the FDA instrument plus manuals. Both carrying cases are very well padded and shadow boxed for each item to fit into the case.

Conclusion. The FilterCHECK 300/EDXRF is an improvement over its predecessor the PRAM beta prototype. The FilterCHECK 300/EDXRF instrument provides the maintainer with a condition based maintainance capability. The FilterCheck 300/EDXRF analyzed over 2000 filters in a year without any system failures. The 1 year warranty placed upon the instrument demonstrates that the manufacturer has a high degree of confidence in the FilterCHECK 300/EDXRF.

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