An SEM Approach to Wear Debris Analysis

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Abstract: There are many approaches for wear-debris analysis. The various techniques require a wide range of technical expertise. This paper describes the use of Scanning Electron Microscopy (SEM) techniques to provide both automated pass/fail reports and a searchable database of individual wear-particle images. The system retains all the desirable features of SEM while permitting routine operation by non-scientific personnel.

Key Words: Scanning electron microscopy (SEM), wear particles

Introduction – The Scanning Electron Microscope (SEM): The SEM is fundamentally an imaging tool, which uses electrons instead of light in order to create highly magnified images. The use of an electron microscope has several advantages over the optical microscope. In the first place, the SEM can provide magnifications far beyond the capability of a conventional microscope and the images have much better depth-of-field at high magnification. In addition, the interaction of the electron beam with the specimen causes the sample to emit highly localized signals, such as x-ray photons, which can be monitored with specialized detectors. The energy or wavelengths of these x-rays indicate the elemental composition at the focal point of the beam.

The SEM can be especially useful for wear particle studies due to its specificity – that is, its ability to characterize a particle population while retaining the distinct characteristics of each particle analyzed. In this way, the size, shape, morphology, and elemental constituents of each particle can be reviewed and can be used for making decisions based on the data generated. When evaluating the trade-offs of using SEM versus conventional wear particle analysis, this specificity must be weighed against the speed and cost of the latter techniques.

The SEM as Particle Analyzer: Historically, one would perform particle analysis by placing a sample in the SEM chamber, and then sequentially observing fields-of-view at a magnification sufficient to see particles of interest. The operator would then zoom up on each feature and place the beam on the sample to collect an x-ray "spectrum" to identify the elements. He or she would then tally that information, perhaps take a photograph, and then move on to the next particle. Clearly, this process is slow, tedious, and error-prone, especially as the operator becomes fatigued.

With the advent of Computer-Controlled Scanning Electron Microscopy (CCSEM) in the 1970s, the tasks of locating particles within a field and collecting x-ray data was automated using grid location and intensity data. Since then automated sample stages, digital SEM control interfaces, and large capacity disk media have brought CCSEM to the state where most aspects of the analysis can be performed in an automated, unattended manner. This is the case with the Personal SEM (PSEM), produced by Aspex LLC. The PSEM, which was the platform used in this study, is widely used for automated feature analysis on a diverse range of materials from concrete to steel to airborne particulate to forensic Gunshot Residue.

However, in spite of the high degree of automation, there is still a significant component of operator set-up required for sample preparation prior to starting the analysis. The location and shape of the sample(s) must be set up, focus and brightness/contrast must be set, and "run parameters" must be chosen. These run parameters describe the microscope settings, elements of interest, time and size criteria, and other analysis control settings. It requires an individual of at least moderate SEM expertise to perform this setup correctly and repeatably. Once setup however, the setup program can be ported to multiple SEM's performing the same task.

The SEM as A Deployable Wear-Debris Analyzer: In order to make the PSEM system perform as a dedicated Wear-Debris analyzer, several design goals had to be achieved:

1) The system needed to be capable of being run by field personnel. These individuals would not have had any classical SEM training, and may be using the system on a transient basis, which did not make it cost- or time-effective to provide such training.
2) A summary report needed to be generated for each sample group, while all images, spectra and numerical information needed to be retained in a searchable data repository.
3) The entire setup must be packaged for reliable field-deployability.

The ideal, from the perspective of the SEM particle analysis, would be to remove all microscope set-up steps from the responsibility of the operator, and permit a "one-button" start-up. In this way, the operator would simply load his or her samples, enter sample ID information in the database, and tell the system to "go".

In order to achieve this, the operator-intensive steps needed to be established before routine analysis could be performed:

1) A sample tray was defined based on the size and shape of the sample for example, a filter patch, a chip detector, etc. The samples are placed in the pre-defined areas on the tray. By knowing the characteristics of the sample tray, the stage-setup could be saved to disk once during calibration, and then simply recalled by the computer automatically for each analysis run. Furthermore, multiple sample trays could be defined, stored, and recalled at will for different sample types.

-- sample tray?--

2) Optimum conditions of beam, working distance, brightness and contrast, and focus were calibrated and stored, to be recalled upon the start of a run. As an adjunct to this, automated procedures were designed to fine-tune the beam, focus, and brightness/contrast on a specialized standard sample that was built into the stage mechanism.

The PSEM was then configured with an external computer as part of a client-server topology. Resident on this external computer is a database, user interface, and PSEM-interface module. The user interacts with this computer to enter sample identification information in a menu-type interface, and then clicks a button to initiate the analysis. The database computer passes the setup information to the PSEM, and instructs it to begin the analysis. The PSEM can then recall all the pre-programmed calibrations and automatically executes the analysis. Thus our non-traditional operator need not interact with the microscope controls to start a run. As the analysis proceeds, all data is shipped immediately to the database computer, where it is processed and stored. When the analysis is complete, the database creates a summary report, which will indicate pass/fail conditions based on pre-programmed criteria, along with a summary of particle types found.

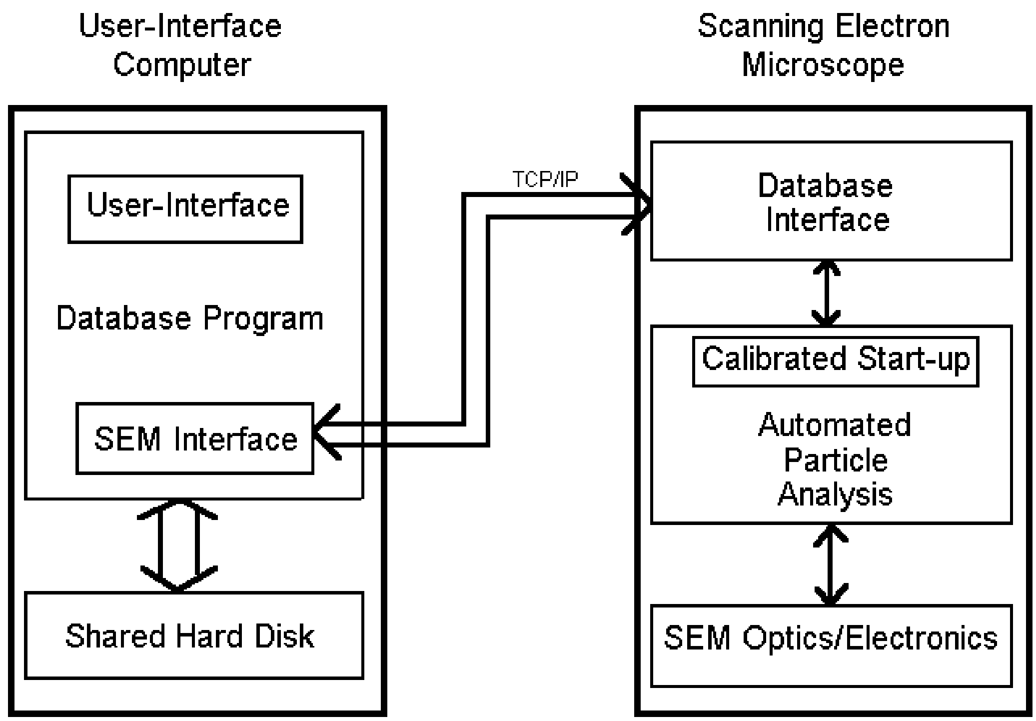


Figure 1: Block Diagram of System Architecture

For most purposes, this is the end of the analysis, and the operator can load new samples and start the process again. If, however, there is an anomaly that warrants further investigation, the database can be queried to display individual particle images and spectra as well as data tables. Since the data and images are in electronic form, they can be shared to remote locations with scientists and engineers to whom particle shape and composition may provide insights, which are not readily discernible in the summary report. Thus we may preserve the essence of the SEM – its imaging capability – while providing a streamlined process for routine analysis and simplified distillation of results.

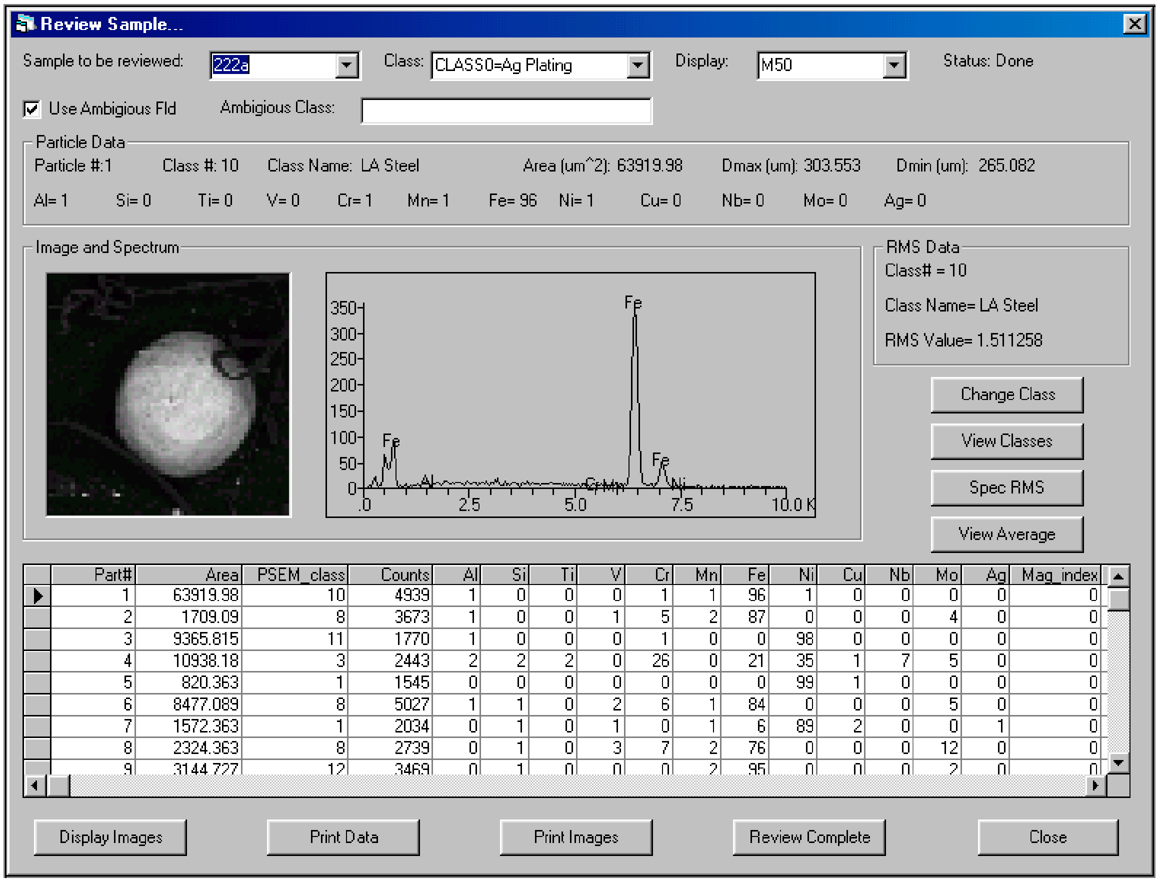


Figure 2: Database – Review Screen illustrating the ability to review images and spectra of individual particles

The SEM and peripherals described above have been built into a rugged enclosure for deployment. The system is shock-mounted and configured such that the stage, gun, and other components are accessible via hinged doors. The SEM monitors are replaced with flat-screens; since these monitors are mainly for maintenance they did not to be as large and clear as those on a non-deployable SEM. Everything in the enclosure is powered by a single electrical cord which plugs into a standard 110 volt outlet.

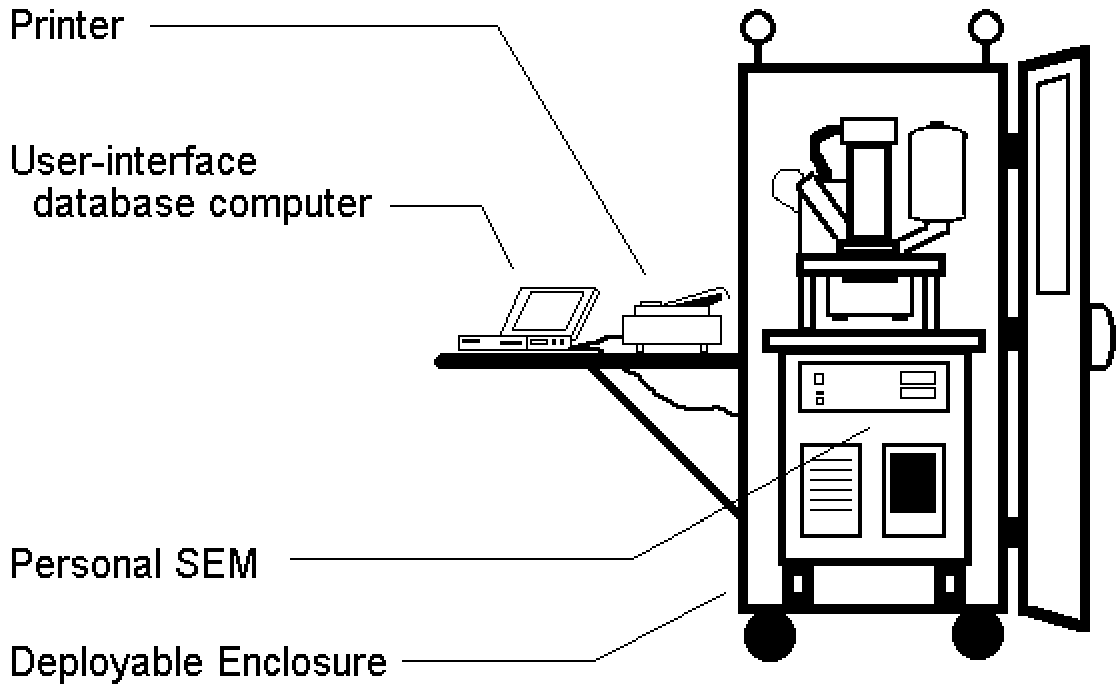


Figure 3: Physical Configuration of System

Figure 4: Actual System

Data From Various Studies

SEMs are being used to successfully identify M50 from pending bearing failures in aircraft engines as well as a variety of other machinery components.

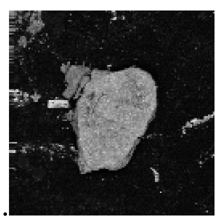
The examples provided below are from:

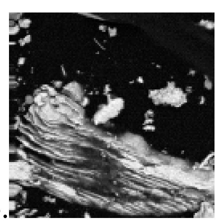
a. An SEM study for USAF Air Combat Command, ACC, on GE F110 engines in F-15 and F-16 weapon systems. SEM was performed on the debris from magnetic chip detectors, MCD.

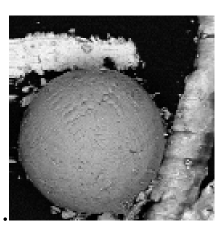
b. Other examples from RJLee?

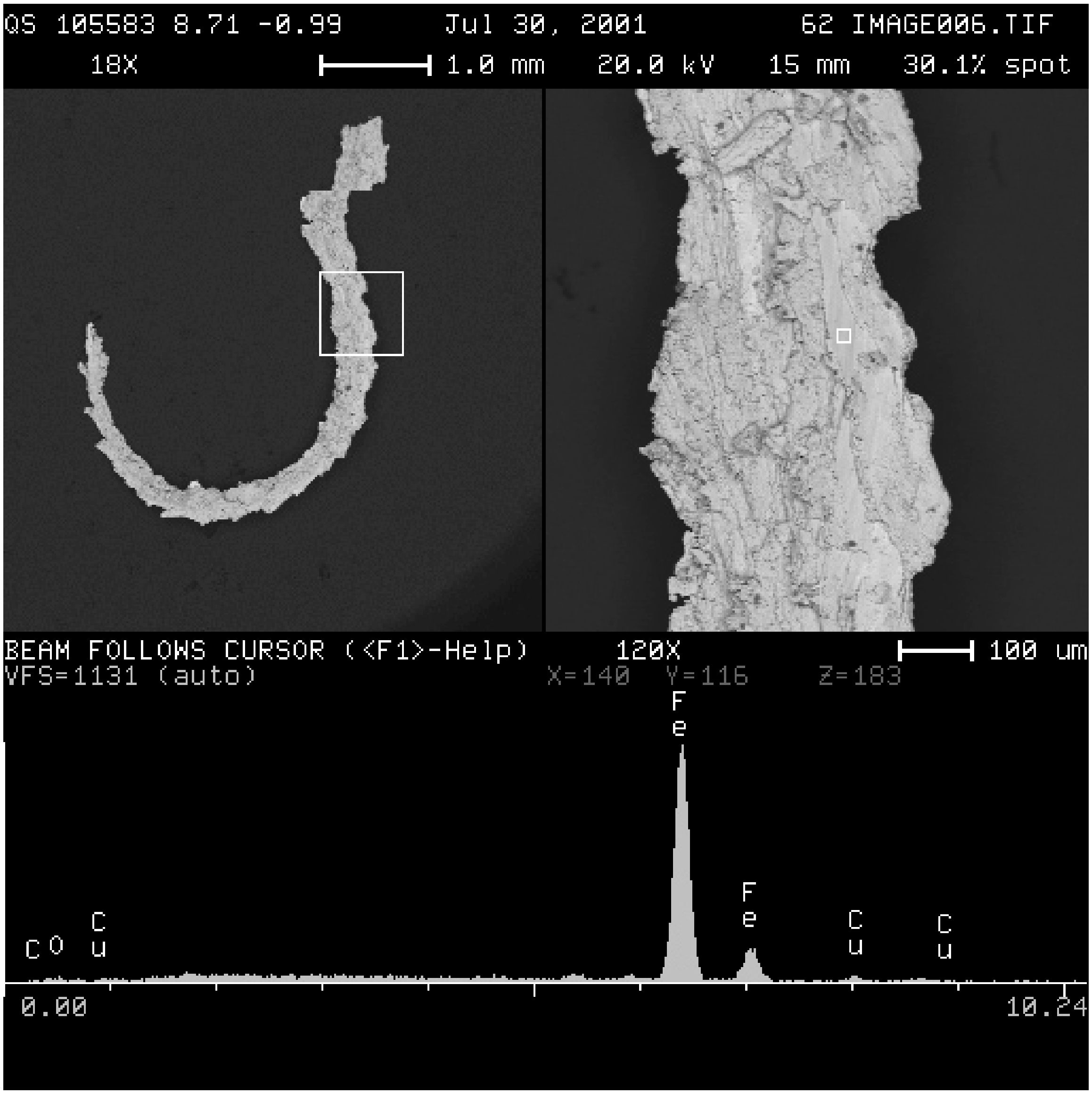
a.1. 
Cutting Wear

a.2. 
Cutting Wear

a.3. 
M50, Sliding Wear – 280sq. 1000^{th} inch

a.4. 
M50 Cutting Wear – 2 sq 1000^{th} inch

a.5. 
AISI 4340 Sphere – 8 sq 1000^{th} inch



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15 mm
30.1% spot
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120X
100 um
VFS=1131 (auto)
X=140 Y=116
Z=183
Fe
Fe
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O
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Cu
Cu
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