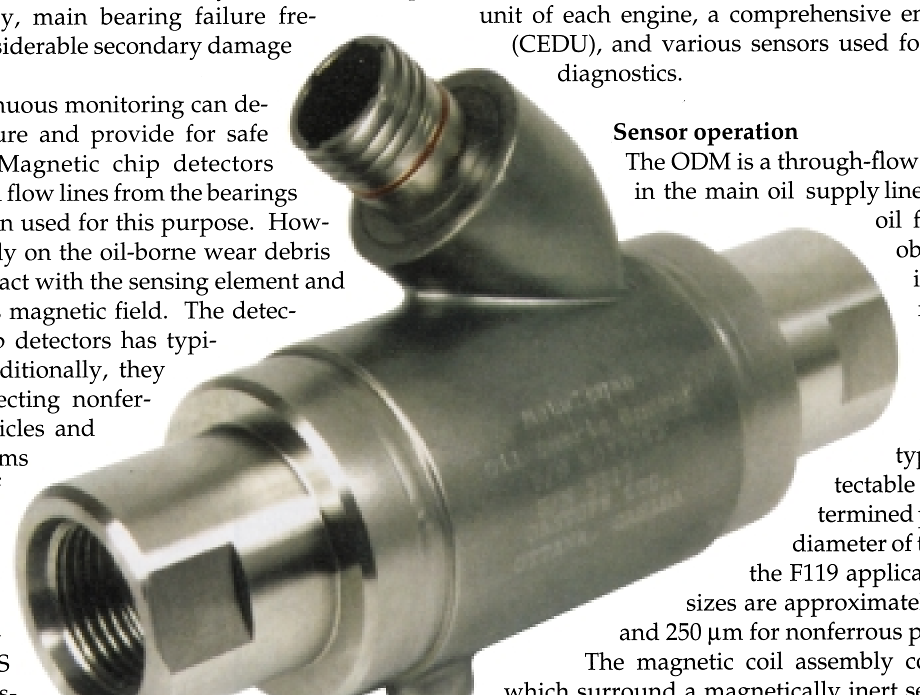
In-line oil debris monitor

A system which detects debris in oil prevents catastrophic engine failure.

The main bearings of an aircraft engine operate under severe conditions of load, speed, and temperature. Under these conditions, component damage can progress rapidly from the time of initial flaw formation to catastrophic failure—sometimes in only a few hours of operation. Additionally, main bearing failure frequently results in considerable secondary damage to the engine.

A method of continuous monitoring can detect the onset of failure and provide for safe engine shutdown. Magnetic chip detectors placed in the return oil flow lines from the bearings traditionally have been used for this purpose. However, these devices rely on the oil-borne wear debris particles to make contact with the sensing element and remain trapped by its magnetic field. The detection efficiency of chip detectors has typically been poor. Additionally, they are incapable of detecting nonferrous wear-metal particles and are prone to false alarms due to the buildup of fine ferrous debris.



A method which enables continuous monitoring within engines is a sensor developed by GasTOPS Ltd. which continuously counts and sizes metal particles in the engines' main oil supplies. The sensor system, called an oil debris monitor (ODM), will be incorporated in the F119-PW-100 Advanced Tactical Fighter (ATF) engine. This is the first time that a production military engine includes an in-line, full-flow oil debris detection capability in the lubrication system of its main oil supply. The ODM senses both ferrous and nonferrous particles.

The ODM will be an integral component of the ATF engine monitoring system (EMS), which provides remote indication of the F119 engine sensor signals, comprehensive on-engine diagnostics, and ground-based fault isolation using flight-recorded data. The EMS includes the full-authority digital engine control unit of each engine, a comprehensive engine diagnostic unit (CEDU), and various sensors used for engine control and diagnostics.

Sensor operation

The ODM is a through-flow device which installs in the main oil supply line and allows the entire oil flow to pass without obstruction. The sensor incorporates a magnetic coil assembly which is capable of detecting and categorizing wear-metal particles by size and type. The minimum detectable particle sizes are determined primarily by the inner diameter of the coil assembly. For the F119 application, these minimum sizes are approximately 125 µm for ferrous and 250 µm for nonferrous particles.

The magnetic coil assembly consists of three coils which surround a magnetically inert section of tubing. The two outside field coils are driven by a high-frequency alternating current source such that their respective fields are nominally opposed or cancel each other at a point inside the tube and just under the center sense coil. Disturbance of the magnetic fields caused by the passage of a particle results in a characteristic sense coil voltage as shown in Figure 1. The amplitude and phase of the output signature is used to identify the size and type of particle. The amplitude of the signal is proportional to the particle's mass for ferrous materials and to its surface area for

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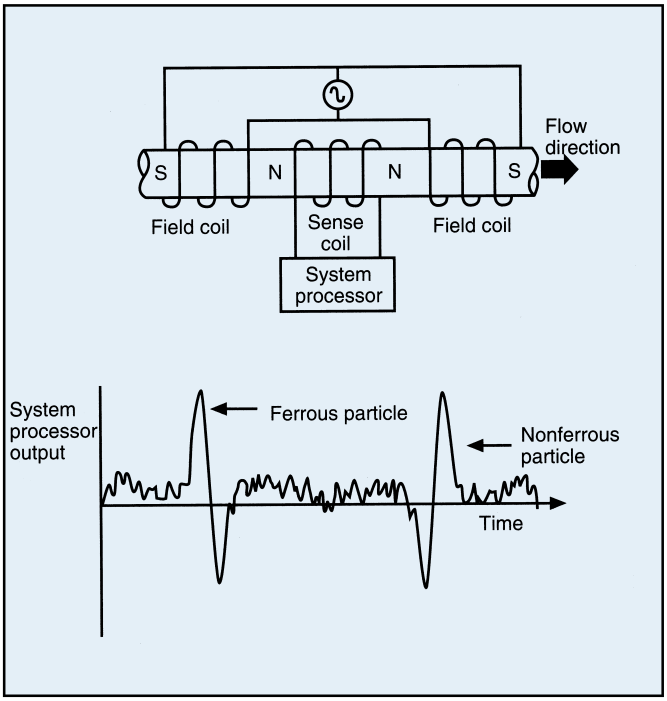

Figure 1. ODM system operation.

nonferrous materials. The phase of the signal for nonferrous particles is opposite that of ferrous ones, allowing a distinction to be made between the two types of wear-metal materials.

Signal conditioning using a threshold algorithm categorizes the particles that pass on the basis of size and type. Several size categories can be defined above the minimum particle size thresholds. After a particle is detected and its size determined, this information is stored in registers or bins which record the total number of detected particles of a given type and bin size.

Mechanical design

The F119 ODM is installed on the housing of the lube oil pump. The oil enters the sensor through a three-bolt flange connection and exits (approximately 8 in. away and rotated by 90°) through a piloted O-ring port.

To accommodate this installation, the ODM was designed as a two-piece unit including a sensor module (Figure 2) and elbow component. The sensor module contains the working elements of the sensor in a welded stainless steel housing designed to withstand the operating environment of the engine and to contain the oil under flame exposure. The unit is designed to minimize exposure of the coils to distortion due to external forces, vibration, and oil pressure fluctuations. The elbow component of the sensor serves as an adapter to the oil pump. It accommodates the 90° rotated flange and allows for flexibility between the two components to accommodate misalignment between the sensor and pump. A spring, combined with the force of the oil pressure, keeps the sensor module in place in the O-ring port during operation. A flexible ground strap and capture mechanism is used to provide the necessary electrical bonding to the engine structure and keep the two sensor components together during installation and removal.

Electronic design

The sensor signals are processed by electronics located in the CEDU. The design that is currently undergoing initial flight-release testing includes two semi-custom ICs which perform the analog and digital ODM processing functions. The analog functions are performed by an application-specific integrated circuit (ASIC) designed by GasTOPS and built by Harris Semiconductor. The ASIC includes electronics to amplify and filter the sensor signals, remove the residual sensor imbalance signal, and extract and detect particle signatures. The digital circuit, a field-programmable gate array, processes the signature outputs, determines the type of particle detected (ferrous/nonferrous), records particle counts, and interfaces with the CEDU microprocessor. The two integrated circuits also work together to provide comprehensive built-in test functions which provide both fault detection and isolation.

The electronics design will be improved for the initial service release version of the F119 ODM. Some of the particle detection functions will be moved into a digital signal processor already present in the CEDU. This change will both simplify the hardware and provide enhanced particle sizing capability.

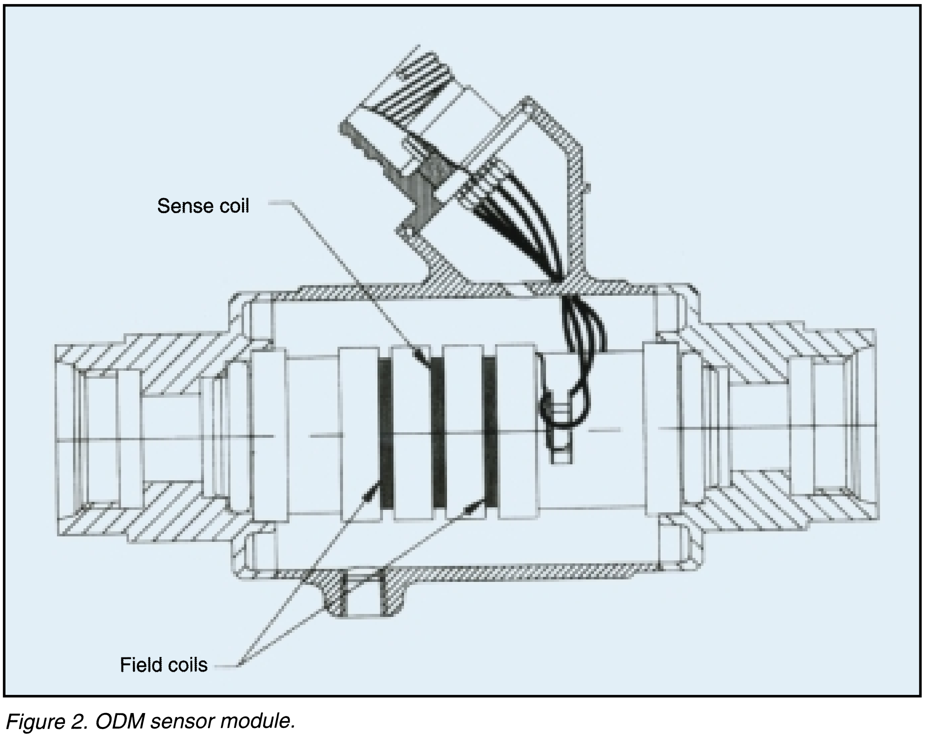

Figure 2. ODM sensor module.

Bearing test program

To establish reliable criteria for warning, alarm, or shutdown conditions based on the ODM output readings, researchers are conducting a test program to investigate the failure of aircraft engine bearings. The program's goal is to quantify the debris released from bearings during failure and to evaluate the ODM's capability to monitor failure progression. Bearings are run past the point of normally accepted failure, and debris released from the bearings is monitored as the failures progress.

More than 40 steel bearings have been run to failure in a test rig specially designed and instrumented for small-scale (2 in. dia.) ball- and roller-bearing tests, as shown in Figure 3. The rig incorporates a fine-mesh screen which captures the debris released during each failure for subsequent comparison to the

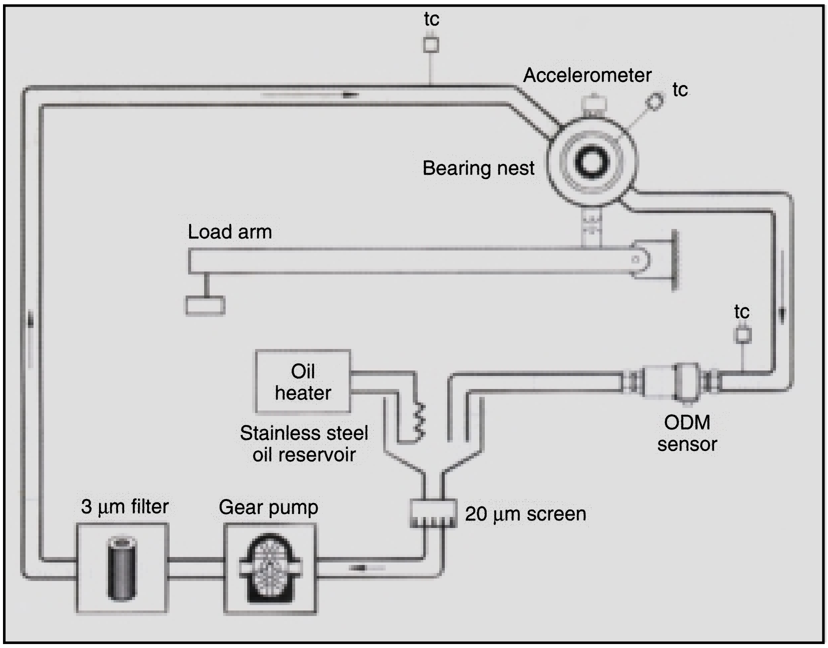

Figure 3. Bearing test rig.

ODM readings. As illustrated in Figures 4 and 5, both the sensor measurements and the findings of the filter debris analysis verify that large numbers of wear-metal particles within the detectable size range of the sensor are released, starting with the first spall, continuing as the bearing is kept in operation, and increasing in rate as damage reaches an advanced state.

The tests have established that the severity of the damage can be correlated to the mass of the wear-metal material removed from the bearing contact surfaces, as shown in Figure 6. This suggests that reliable caution and alarm thresholds can be established based on the cumulative mass of debris measured by the ODM.

A single test was conducted by Pratt & Whitney on a large-diameter thrust bearing from an aircraft engine application. The bearing material was steel, and failure was initiated by intentionally damaging each of the functional surfaces of the bearing (inner race, outer race, and balls) using 0.025-in.-dia. indents. The rig was operated at maximum bearing load conditions until vibration levels reached approximately 50 *g*, at which time the rig was shut down and the bearing inspected. Inspection of the bearing following the test revealed extensive inner race spalling, outer race distress, ball spalling, flaking, and cage fracture.

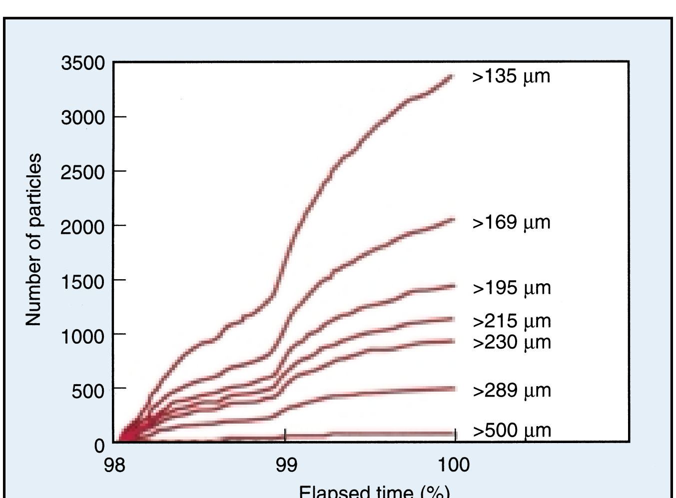

Figure 4. Sensor output during bearing test.

Figure 7 shows the number of particles generated above each of the ferrous particle thresholds used for the test. As indicated, the sensor detected the initial spall and counted significant numbers of wear-metal particles greater than 200 µm throughout the failure. In total, over 150,000 ferrous particles greater than 200 µm and more then 25,000 particles larger than 700 µm were counted. Also of note was the rapid increase in the rate of particles counted later in the test.

A single test was also conducted on an advanced-technology hybrid bearing for aircraft engine application. Failure of this bearing, which incorporated ceramic balls and steel races, was initiated by a series of 0.02-in.-dia. stress concentration pits created on the bearing's inner race. The bearing was run progressively from the point of initial spall to a point at which severe spalling damage was evident over roughly 10% of the race circumference.

Figure 8 shows the number of ferrous particles generated above each of the size thresholds used for the test. Over the course of the test loop more than 7000 particles greater than 200 µm and over 100 particles greater than 700 µm were counted by the sensor. As in the case

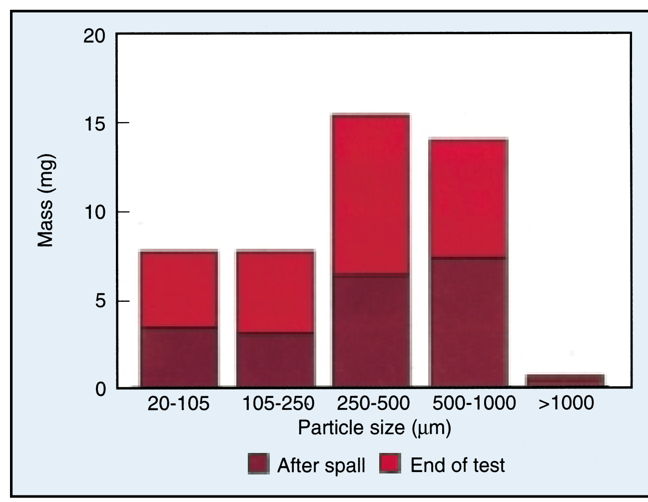

Figure 5. Filter backwash results.

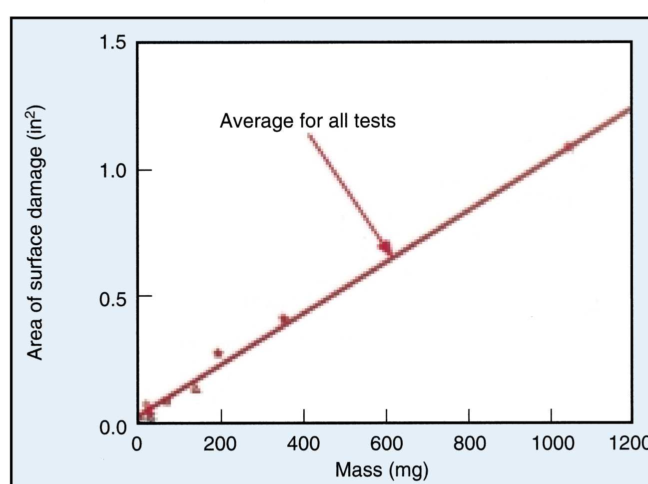

Figure 6. Correlation between sensor output (mass) and observed surface damage.

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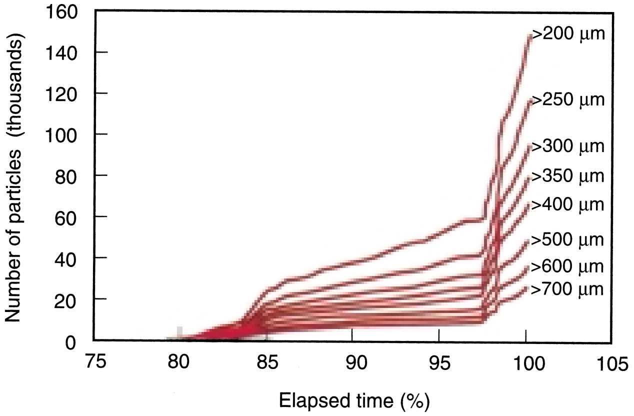

Figure 7. Large-scale bearing test results.

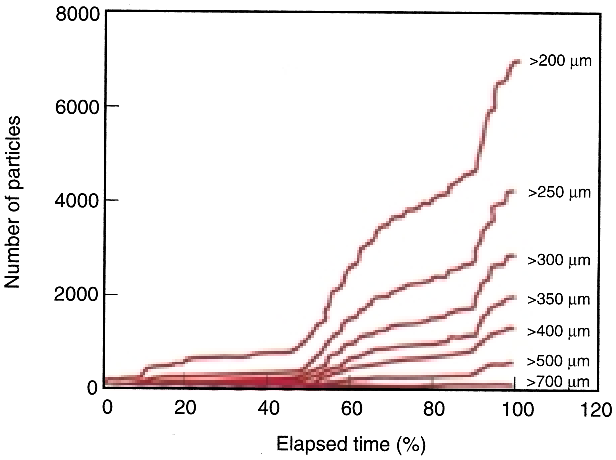

Figure 8. Hybrid bearing test results.

of the large-scale bearing test, a significant increase in the rate of particles counted during the latter stages of the failure was evident.

The ODM has successfully completed the preflight engineering test and evaluation phase of the engine's full-scale development program. Pratt & Whitney will conduct flight qualification testing of the initial flight-release hardware. First flight of the ODM is planned for 1997. GasTOPS has also entered into a formal partnership agreement with BFGoodrich Aerospace for ongoing development and production of the ODM for aerospace applications. □

Information for this article was provided by **Dave Muir**, GasTOPS Ltd. and **Brad Howe**, BFGoodrich Aerospace.