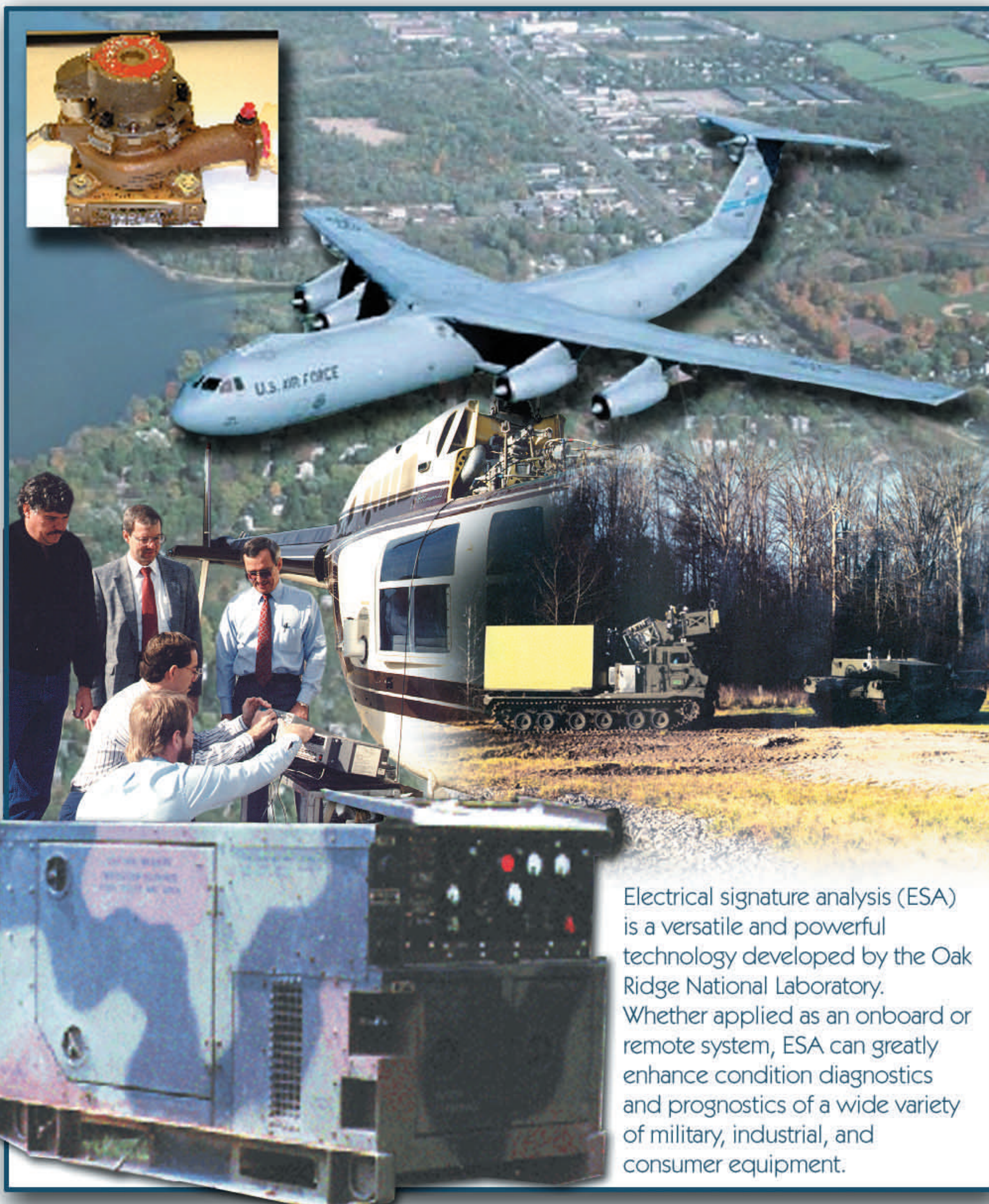
Electrical Signature Analysis

for Condition Monitoring and Condition-Based Maintenance



Electrical signature analysis (ESA) is a versatile and powerful technology developed by the Oak Ridge National Laboratory. Whether applied as an onboard or remote system, ESA can greatly enhance condition diagnostics and prognostics of a wide variety of military, industrial, and consumer equipment.

Electrical Signature Analysis (ESA)

Electrical signature analysis (ESA), a versatile and powerful, yet truly non-intrusive, technology pioneered at Oak Ridge National Laboratory (ORNL) can be readily integrated into most electro-mechanical equipment to greatly enhance condition diagnostics and prognostics capabilities. ESA provides diagnostic and prognostic information comparable to conventional vibration analysis but requires only access to electrical lines carrying input or output power rather than to the equipment itself. Thus, either onboard or remote analysis is possible—even continuous monitoring if desired. ESA has already been tested on and successfully applied to a wide variety of systems, including military, industrial, and consumer equipment.

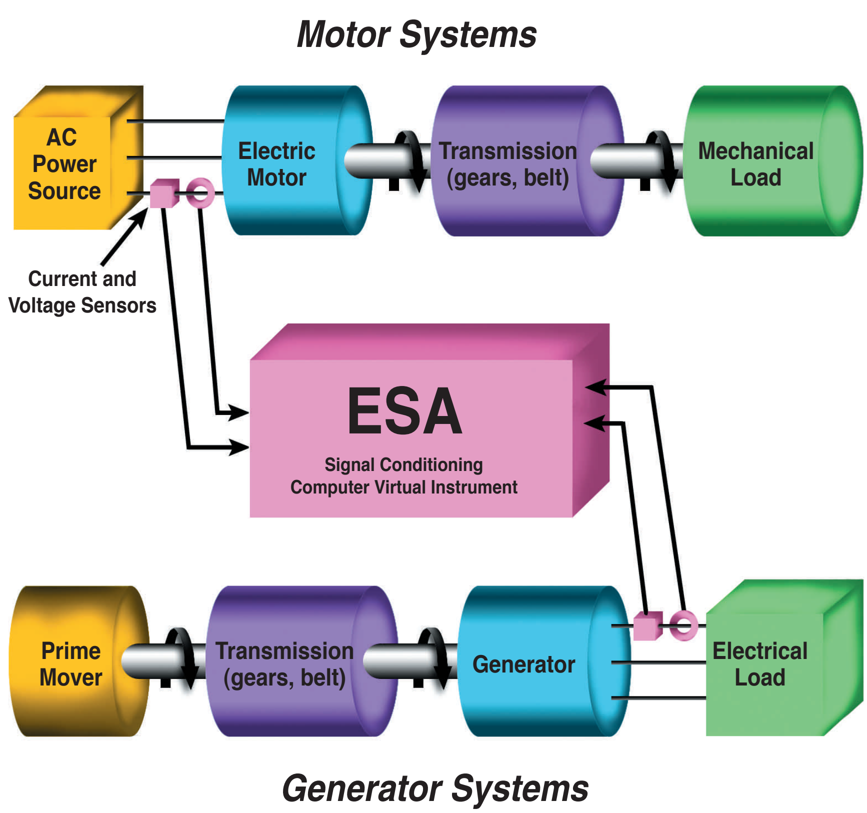
Load and speed variations in electro-mechanical systems generally produce correlated variations in current and voltage. ESA analyzes these small perturbations and matches them to their source. The resulting time and frequency signatures reflect loads, stresses, and wear throughout the system and allow an extensive range of mechanical diagnostic information to be obtained from a single sensor attached to an electrical line.

Few available technologies can be so seamlessly integrated into existing maintenance programs. With the addition of a few sensors, ESA diagnostics can pinpoint electrical and mechanical problems and target maintenance on an as-needed basis, thereby increasing equipment reliability and maintenance efficiency and minimizing unexpected downtime.

Technical Basis

ESA provides a breakthrough in the ability to detect and quantify mechanical defects and degradations in electro-mechanical equipment and unwanted changes in process conditions. ESA is truly non-intrusive and does not interfere with the operation of the equipment being monitored.

As a result of continued R&D by the Oak Ridge National Laboratory (ORNL), ESA has matured as a diagnostic/prognostic technology. ORNL has developed several signal conditioning and signature analysis methods to capitalize on the intrinsic abilities of conventional electric motors and generators to act as transducers. Time-dependent load and speed variations occurring throughout an electro-mechanical system will generally induce small variations in the motor's and/or generator's electrical response. These variations are observed as a change in current (for a motor) or a change in voltage (for a generator). ORNL researchers have pioneered the development and application of signal conditioning techniques for extracting these small electrical perturbations and relating them to their source and have thus opened a new field for diagnostic innovations.



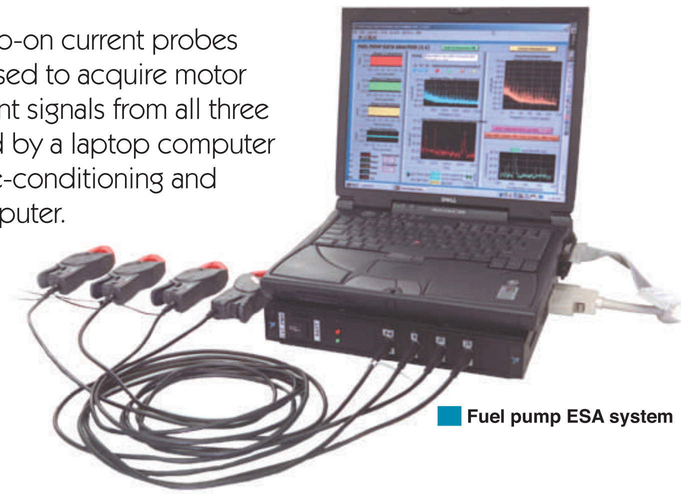
Applications

Aircraft Fuel Pumps provide fuel to multiple engines from the wing fuel tanks. A total of twenty pumps are used in the C-141 Starlifter, with one primary pump and one secondary pump in the main and auxiliary fuel tank for each of the four engines and in the extended range fuel tank in each wing.

C-141 Starlifter and Auxiliary Fuel Pump

ORNL has successfully demonstrated the use of ESA techniques as a method for diagnosing faults in C-141 fuel booster pumps with funding from the Air Force. Motor current spectra were found to be rich in identifiable features that relate to pump design and condition. Correlations have been found between motor current components, pump performance, and degraded condition; therefore, ESA is expected to become a useful tool for the Air Force in performing fuel pump diagnostics and prognostics.

Clamp-on current probes are used to acquire motor current signals from all three phases, plus neutral. Data acquisition and analysis is performed by a laptop computer running specially developed ESA virtual instruments. Signal pre-conditioning and interfacing is handled by an I/O chassis that sits below the computer.

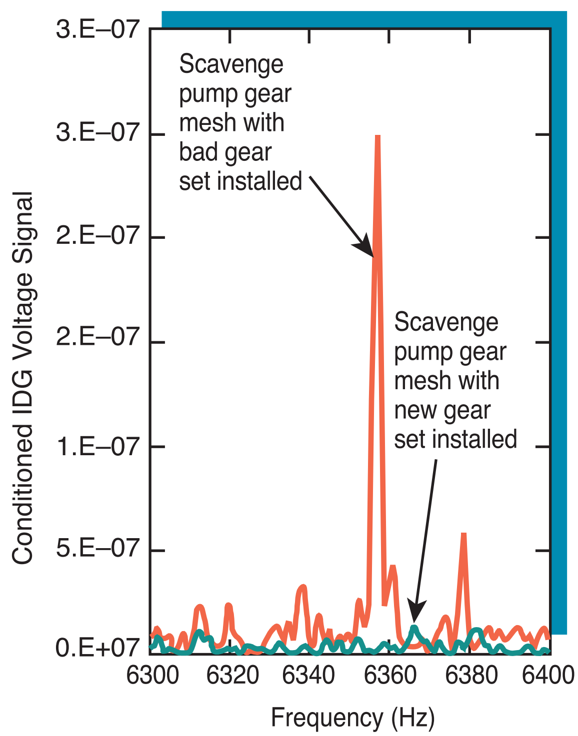


Fuel pump ESA system

ORNL is developing ESA algorithms and diagnostic procedures based on field and laboratory testing. Together with Air Force engineering and maintenance personnel, ORNL plans to develop a specification for a field-ready ESA-based diagnostic instrument that can be integrated into their fuel pump maintenance processes.

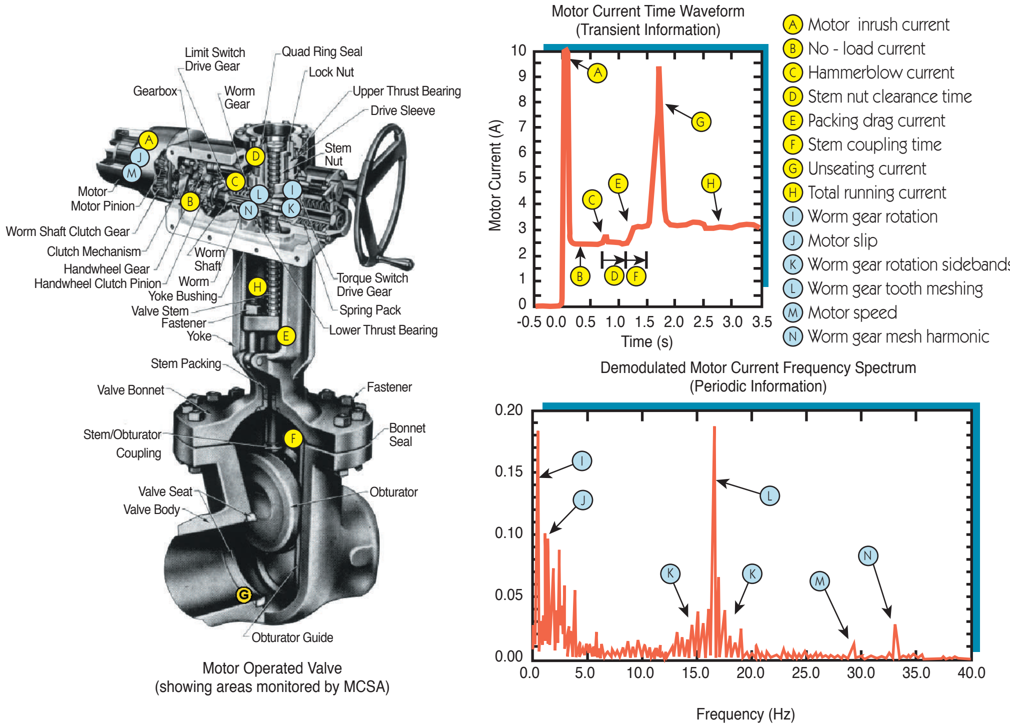
Integrated Drive Generators (IDGs) on certain aircraft experience complete failure, on average, at a rate of four per year; as many as ten have failed in one year. The causes are seizure and destruction of scavenge, drive pump, and axial gears on the generator's main shaft. Traditional re-certification tests do not detect incipient gear failure. If the $17,000 gear sets seize, the $250,000 IDG is essentially ruined. The capability to predict gear failure or incipient failure represents substantial savings for owners in replacement costs.

IDG units provide power to commercial aircraft (117/208 volts at 400 Hz) for passenger reading lights and galley microwave ovens. To maintain their reliability, effective measures of the onset and levels of gear wear are needed. ORNL has demonstrated both on a test stand and on a jet that ESA techniques provide signature attributes necessary to characterize good and worn gears. The strength of ESA is that current and voltage probes are easy to attach and use for monitoring, with no additional mounting required. Results show that even at extremely low generator loads, ESA provides excellent sensitivity to the gear-related problems.



The scavenge pump gear-mesh peak in the IDG voltage spectrum was used to detect a bad gear set

Applications – continued



Motor current time waveforms and frequency spectrum for a motor-operated valve (MOV) showing multiple locations where degradation can be detected

Motor-Operated Valves are used in large numbers throughout many industries. In the mid 1980s, the Oak Ridge National Laboratory (ORNL), with funding from the U.S. Nuclear Regulatory Commission, evaluated methods for monitoring aging and service wear of nuclear power plant motor-operated valves (MOVs). In addition to evaluating standard condition monitoring methods employing equipment-mounted sensors, ORNL researchers focused their efforts at developing diagnostic techniques that used the motor's running current, since it could be acquired remotely and non-intrusively. These new techniques provided a breakthrough in detecting load and speed variations generated anywhere within the MOV and converting them into revealing "signatures" that could be used to detect component degradation and precursors to MOV failures. ORNL named this new monitoring technology Motor Current Signature Analysis (MCSA), a term that is widely used today to refer to motor current based methods for monitoring the condition of electric motors. MCSA was shown by ORNL to provide the sensitivity necessary to detect a large variety of MOV problems including gear wear and binding, degraded lubrication, over-tightened stem packing, valve seating problems, bent valve stem, improperly set switches, etc. The successful application of MCSA as a monitoring technology for MOVs provided a foundation on which additional tools were developed by ORNL for monitoring and analyzing electrical current, voltage, and power signals. These developments are applicable to both motor and generator systems, and now comprise a powerful technology suite called Electrical Signature Analysis (ESA).

Other applications of ESA demonstrated by ORNL include:

- Helicopter (Rotor and Gear Train)
- Army Portable Power Generator-Sets
- Navy Fire and Seawater Pumps
- NASA propellant control valve
- Heat Pump and Air Conditioning Systems
- Variable Speed Motors
- Air Compressors
- Army Ammunition Delivery Systems
- Large Compressors (Rotating Stall Detection)
- Other Water and Fuel Pumps
- Diesel Engine Starter Motors
- Large Blowers and Fans
- Multi-axis industrial cutting machines
- Electric Vehicle Motors and Alternators

How to Contact Us

If you would like additional information on ESA and would like to find out how ESA can help you minimize unexpected failures, increase equipment reliability, and reduce unscheduled downtime, please contact

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Aircraft Electric Fuel Pump Condition Monitor using ORNL Electrical Signature Analysis

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The Oak Ridge National Laboratory (ORNL) and the U.S. Air Force has established a project to evaluate, adapt, and apply ORNL developed technology to decrease the burden of unplanned C-141 aircraft maintenance due to electric fuel booster pump failures.

Fuel is delivered to the four C-141 aircraft engines by means of 20 electric fuel booster pumps that are completely submerged inside the wing fuel tanks. A study by the Air Force has documented that fuel pump failures alone for the C-141 aircraft have accounted for approximately 4000 hours of aircraft unscheduled downtime, which has a potential loss of airlift services revenue worth approximately two million dollars per year.

At the present time, C-141 fuel pumps are run to failure, since no comprehensive test method is available to the Air Force for evaluating their condition while still installed in the aircraft. Failed pumps are shipped to an Air Logistic Center (ALC) for refurbishment. Since the cause of these fuel pump failures is often unspecified, failed pumps may undergo an entire replacement of key parts. Even so, refurbished fuel pumps can occasionally fail certification testing, and must be disassembled and refurbished again. In addition to the inconvenience and cost of unexpected pump failures, this maintenance approach is time consuming and wastes valuable spare parts.

The ORNL Fuel Pump Condition Monitor (FPCM) is a self-contained portable system for acquiring and analyzing fuel pump motor current data. The system includes a rugged military-style laptop computer that contains novel ORNL-developed motor current signature analysis software that is specific to the aircraft application, custom-designed signal conditioning electronics (SCE), and inductive current probes that are clamped around the fuel pump power leads. The system components are contained in an environmentally sealed suitcase-style case.

ESA allows the user to determine the electrical and mechanical condition of the monitored fuel pump from the motor current signals alone. Thus, the FPCM is the first test instrument capable of performing comprehensive in-situ condition assessments of C-141 fuel pumps.

With minor software modifications, the ORNL FPCM will be applicable to a wide variety of fuel pumps used on other aircraft and in other equipment. With more elaborate software changes, the same hardware platform established by the FPCM would be applicable to diagnostic testing of other aircraft electrical and electro-mechanical equipment such as flight control surface drive actuators, landing gear bay door actuators and landing gear retraction mechanisms, electric motor-driven hydraulic pumps, integrated drive generators (IDGs), electric fuel shutoff valves, etc.