MANUFACTURING TECHNOLOGY FOR NONDESTRUCTIVE EVALUATION (NDE) SYSTEM TO IMPLEMENT RETIREMENT FOR CAUSE (RFC) PROCEDURES FOR GAS TURBINE ENGINE COMPONENTS

Donald L. Birx and Dena G. Doolin

NDE Systems Division
SYSTEMS RESEARCH LABORATORIES, INC.
2800 Indian Ripple Road
Dayton, OH 45440

INTRODUCTION

Systems Research Laboratories, Inc., with a team of subcontractors, has developed an automated NDE inspection system to detect surface flaws and inclusions in jet engine rotary parts. The system implements the Air Force Retirement for Cause philosophy in which good, used engine parts are returned to service, and flawed components are retired for cause. Emphasis has thus been placed on improving current flaw detection and characterization techniques by using computer algorithms (removing the human decision process) and achieving basic inspection and predictive capabilities via automated eddy current and ultrasonic inspection techniques.

The RFC/NDE Inspection System includes both state-of-the-art and proven NDE instrumentation and flaw detection/characterization techniques. The system is modular, uses standard communication interfaces, and has extensive computer capability to provide for future expansion, upgrade and modification. Backup capability, maintainability, and reliability have also been built into the system. Backup capability (50% throughput in the event of any major module or peripheral failure) is assured through redundant communication interfaces, inspection stations, and system computers. Maintainability is assured through self-diagnostics, simplicity, and a design influenced by a factory operating environment. Flaw detection reliability will be assessed using part specimens containing representative flaw geometries, and flaw analysis techniques including Least-Squares Log-Odds Mean Curve, Maximum Likelihood Estimator Log-Odds Mean Curve, and Least-Squares Log-Odds 90/95 Lower Bound.

In essence, the RFC/NDE Inspection System applies the latest laboratory technology to an industrial environment. It is a highly technical and mechanically complex system, yet operates with the apparent user simplicity and ruggedness characteristic of an industrial machine.
SYSTEM DESCRIPTION

The RFC/NDE Inspection System was designed per structured analysis methodology and consists of an Operator Console, 2 System Computers, 3 Eddy Current and 2 Ultrasonic NDE Inspection Stations.

Figure 1. RFC/NDE INSPECTION SYSTEM

The Operator Console is a passive station used primarily to monitor the system's operational status, track the individual part inspections at the NDE Stations, and generate part inspection data reports.

Figure 2. OPERATOR CONSOLE

The console has 4 color CRT displays functionally dedicated as follows. The Main Menu is a command-driven display used to generate part inspection data reports and graphic displays from previous part inspections. The Part/Defect Graphics Display provides color displays of part inspection
results as they are generated at the NDE Inspection Stations. This display contains top- and side-view illustrations of the engine part with color-coded geometric flaw locations. The display also includes specific part inspection summary data such as relative flaw sizes and locations, inspection start/stop times, the cumulative number of part inspections, the date of inspection, and the part accept/reject decision. The System Diagnostic Display provides a continuously updated operational status display of the inspection system including the communication network, and the Inspection Status Display shows the current status of the part inspections at each NDE Inspection Station.

The Operator Console also has a 2-way intercom system for communication with the NDE Inspection Stations; a color printer/plotter for hardcopy color graphic print outs; and a line-printer for part inspection data reports. The Operator Console's software resides on the System Computers and all communication between the System Computers and Operator Console is done over an RS232 data transfer link.

The dual VAX 11/780 System Computers provide the central intelligence for the entire RFC/NDE Inspection System. They perform advanced data processing, system-wide communication, and sophisticated, high-speed mathematical and scientific data analysis critical to the inspection process. The primary tasks of the System Computers are part tracking, Operator Console/NDE Inspection Station interface and communication, NDE data cross-correlation, archival data base storage, system diagnostics, advanced signal processing, RFC proprietary data analysis, and graphics processing.

![Figure 3. VAX 11/780 SYSTEM COMPUTERS](image)

Each VAX 11/780 combines a 32-bit architecture, efficient memory management, and a virtual memory operating system to provide essentially unlimited program space. The VAX/VMS virtual memory operating system provides the multiuser, multiprogramming environment critical to the RFC System's application. In addition, the VAX floating-point instructions and accelerators, efficient scheduler, and FORTRAN-77 programming language are ideal for the System's realtime and scientific computational environments.

879
The combined disk space for the dual-VAX configuration totals 1,446 MB. The permanent on-line storage space has been dedicated to storing all archival data, RFC-application software, and engine manufacturer proprietary data thus ensuring ready-access and increased software security. The removable disks have been allocated for part-specific scan plan software storage thus providing easy software update and file expansion.

The dual-RS232 optical links provide the system-wide communication network between the System Computers and the NDE Inspection Stations. This dual structure provides enhanced system performance, increased data transfer rates, flexibility, and the capability to map functional elements around failed components. The communication link between the 2 VAX Computers is DECNET, and as stated earlier, a dual-RS232 serial link provides the communication between the System Computers and the Operator Console.

The RFC/NDE Inspection System employs both eddy current and ultrasonic inspection techniques to inspect the jet engine rotary parts. Ultrasonic "squirter" technology is used to detect volumetric flaws and voids, eddy current is used for surface flaw detection. The RFC System consists of 5 NDE Inspection Stations (3 eddy current and 2 ultrasonic). Each eddy current and ultrasonic inspection station consists of a mechanical module and an instrumentation cabinet.

Figure 4. EDDY CURRENT INSPECTION STATION
The eddy current and ultrasonic mechanical modules consist of an X-Y-Z axes mechanical manipulator (manufactured by M&M Precision Systems, Inc.) and the following subassemblies:

The eddy current module has 7 primary subassemblies which are mounted directly to the base manipulator. The eddy current rotary scanner physically couples the probe to the mechanical manipulator and electronically couples the flaw signals to the eddy current instrument. The scanner has a C drive mechanism for rotating RECHII probes up to 1500 rpm, an air plenum to supply air to the air-bearing surface probes, and rotary transformers and specialized printed circuit cards for signal transfer and enhancement.
The calibration plate assembly consists of a metal riser upon which calibration plates with known flaws are mounted. The calibration plates are used to do a 2-point calibration of the eddy current instrument and an operational check of the probes prior to and following a part inspection.

The rotary table/part fixture assembly clamps and rotates the engine part during an inspection. The rotary table can operate in either a continuous rotation mode (at 0 to 20 rpm) or an index mode. The part fixture is a pneumatic system which automatically clamps the part (either on the outer diameter or inner diameter as required) to the rotary table.

The probe changer is a carousel assembly which holds up to 24 eddy current probes on its outside diameter. The probe changer automatically indexes the correct probe into position for retrieval by the mechanical manipulator. The bar code reader scans each probe in the probe changer prior to the part inspection to ensure correct probe placement by the operator.

The laser pointer is a low-power coherent laser which emits a thin beam across the engine part after the part has been placed on the part fixture. The beam assists the operator in properly aligning the part on the fixture prior to clamping.

The B-Z' assembly provides the robotic wrist action for the eddy current mechanical manipulator. The B axis rotates in a sweep pattern parallel to the X axis and the Z' provides a linear thrust motion on the B radial.

The ultrasonic mechanical module has 6 major subassemblies, 2 of which (the rotary table/part fixture assembly and the laser pointer) are identical to the eddy current module. The 4 subassemblies which are

![Diagram of Ultrasonic Mechanical Module]

Figure 7. ULTRASONIC MECHANICAL MODULE
unique to the ultrasonic station are the calibration plate assembly, the water pump/filtration assembly, the splash guard/drip tray assembly, and the A-B axes gimbal assembly. The ultrasonic calibration plate assembly is mounted inside the splash pan assembly and is used for squirter/NDT instrument calibration prior to and after each part inspection. The block contains 4 interior voids that are 20 mils in diameter and 1/2 inch deep.

The water pump/filtration assembly circulates and cleans the water during the squirter inspection process. The splash guard/drip tray assembly fits around and under the rotary table and catches the water used during the part inspection and returns it to the pump/filtration assembly.

The A-B axes gimbal assembly physically couples the squirter to the mechanical manipulator and provides the mechanical robotic wrist action for the X-Y-Z manipulator. The A axis has a 60° range of motion and the B axis has 130°.

The ultrasonic and eddy current instrumentation modules are the inspection station operator’s control module. Each module contains an inspection module computer, an audio/visual alarm system, a color CRT display monitor, an operator pushbutton control panel and auxiliary keyboard, an intercom system to the Operator Console, the mechanical module’s controller, and an NDE Instrument.

The RFC System’s eddy current and ultrasonic NDE instruments represent the most advanced computer-controlled instrumentation available. The eddy current instrument is the NORTEC NDT-25 with dual channel digital sampler. The NDT-25 is a computer-controlled instrument with a frequency

Figure 8. INSTRUMENTATION MODULE
range of 10 KHz to 6 MHz. The ultrasonic instrument, the SRL Model 1712A Computerized Ultrasonic Instrument (CUI), is computer-interfaceable and contains a microprocessor-controlled, square-wave pulser, high-speed digital sampler (55 MHz), and multibus-compatible receiver boards.

The Inspection Module Computers provide local module intelligence and operator communication for the NDE Inspection Stations. The computer is an Intel 86/380 microprocessor which contains multiple Intel microcomputer boards for individual processing functions (e.g., I/O, mechanical system scan control, and instrument control) and specialized instrument boards. The Intel 86/380 System features a 32 MB Winchester disk drive, 1 MB floppy disk, iRMX operating system, and 12 multibus card slots for specialized user functions. The Intel 86/380 delineated functions, modularity, and component board plug-in capability enhance modification, diagnosis, and repair of the Inspection Module Computer.

The RFC System's data acquisition module includes all probes and transducers used for flaw detection, adaptive positioning, dimensioning and scanning. Advanced technology that has been incorporated into this module include Southwest Research Institute's air bearing probes and ultrasonic squirter, NORTEC's RECHII probes, and SRL's ultrasonic squirter.

CONCLUSION

The RFC/NDE contract was awarded to SRL in October 1981. During the first 2 years of the program, major effort was directed toward organizing and coordinating subcontractor program activities, establishing the core in-house project team, defining the inspection system's performance criteria and specifications, and designing and fabricating the prototype inspection system.

In March 1984, the prototype system, which consisted of 1 eddy current and 1 ultrasonic inspection station, the operator console, and 1 VAX 11/780 system computer, was successfully demonstrated to Air Force and subcontractor program participants. During 1984 and 1985, SRL has performed an in-depth performance evaluation and system upgrade to meet production inspection performance specifications. Initial system delivery to Kelly Air Force Base, San Antonio, Texas, is scheduled for fall 1985 with system integration/implementation activities scheduled to continue through the remainder of 1985. The RFC/NDE Inspection System is scheduled to begin actual production operation in March/April 1986.