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AUTOMATIC ULTRASONIC TESTING AND THE LOFT IN-SERVICE INSPECTION PROGRAM

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ABSTRACT

An automatic ultrasonic testing system has been developed which significantly improves the flaw indication detection and characterization capability over the capability of conventional volumetric examination techniques. The system utilizes an accurately located ultrasonic sensor to generate the examination data. A small computer performs and integrates control and data input/output functions. Computer software has been developed to provide a rigorous method for data analysis and ultrasonic image interpretation. The system has been used as part of an in-service inspection program to examine welds in thick austenitic stainless steel pipes in a small experimental nuclear reactor.

NOTICE

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INTRODUCTION

A computer controlled automatic ultrasonic testing (AUT) system has been developed which provides significant advancement of field volumetric nondestructive examination techniques over current conventional techniques. The system vastly improves indication detection and characterization capability by providing precision orientation of the ultrasonic transducer and by improving data recording, reduction, display, retention, and interpretation capabilities that fulfill inspection requirements of Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (the Code). The Code imposes quantitative requirements on ultrasonic testing performed on nuclear reactor components. The size, shape, location, and orientation of relatively small indications within thick sections must be quantitized.

Conventional ultrasonic testing techniques, particularly for field applications, have been primarily qualitative and semi-quantitative, the measurement integrity highly dependent on the skill and attentiveness of the operator. Experience in in-service inspections indicates that ultrasonic testing results under field conditions are highly variable and imprecise.

To overcome these deficiencies, an AUT system has been developed and utilized for field use on the Loss-of-Fluid Test (LOFT) Facility, a small conventional light water pressurized reactor. The main purpose of the AUT system is to provide improved inspection accuracy and reproducibility of ASME Code Class 1 weld examinations particularly in thick stainless steel sections.

The AUT system will be described along with the LOFT AUT program including system objectives, advantages and limitations, operating experience, and future work scope.

SYSTEM DESCRIPTION

The LOFT reactor is a 50-MW (thermal) pressurized water reactor schematically depicted in Figure 1. The intact loop, containing the primary coolant pumps, pressurizer, and steam generator, simulates three loops of a four loop pressurized water reactor. The broken loop, containing the steam generator simulator, the primary coolant pump simulator, and the quick opening blowdown valves, usually simulates the broken loop of a four loop pressurized water reactor. This reactor system was utilized to gain field operating experience with the LOFT AUT system.

General AUT System Concepts

The AUT system is defined as a computer controlled, ultrasonic imaging system designed to provide reliable, quantitative characterization of flaws in field use on nuclear reactor components.

Three general system concepts constitute the AUT system. First, the mechanical system provides precise control and reproducibility. Second, the control and recording system acquires, analyzes, and displays all data in a readily retrievable form. Third, the data analysis and graphics system integrates the data and presents it to the operator in a permanent, reproducible, readily interpretable form.

Principal System Components

The principal components of the system diagramed in Figure 2 are grouped by the general functions of data sensing, data transfer, control, and data input/output.

Data Sensing

The data sensing function is performed by the search head. The search head installation depicted in Figure 3 requires a 13 cm annular clearance around the pipe and a 26 cm axial clearance adjacent to the weld. Full 360° circumferential clearance is not essential. The search head possesses four degrees of freedom: axial and circumferential with respect to the pipe and two angular degrees. All four motions are controlled by stepping motors using position encoders in a digital computer controlled feedback system. Figure 4 illustrates a portion of the drive system of the search heads. Figure 5 shows the search wheel internals including the baffle and collimator design which eliminates most internal acoustic echoes. The current search head designs can examine 20 to 46 cm diameter pipes. For pipes less than 20 cm diameter, new search heads and head tracks need to be designed. For pipes greater than 46 cm diameter, new search head tracks need to be designed.

Data Transfer

The data transfer function is performed by the pulser/receiver, range gate analog-to-digital converter, and an on-line scan display system. The pulser/receiver provides a video analog signal that is converted by the analog-to-digital converter to a digital value selected by the control computer program. The on-line scan display is used to monitor the pulser/receiver output signal.

Control

The control function is provided by the mechanical control, status unit and the computer. The control-status unit provides remote manual control of all four degrees of freedom of the search head and provides numerical display of all four of the same motions. The computer through its software directs the ultrasonic beam positioner. The computer also integrates the complete AUT process and, in effect, provides the examination and analysis procedure.

Data Input/Output

The data input/output function is performed by the graphics display system, disc system, and tape units. The graphics display system provides data and data analysis display capability and man/machine interface capability. This display system includes a high speed line printer. The disc and tape systems provide mass memory capability.

LOFT AUT PROGRAM

The main purpose of the LOFT AUT program is to provide accurate and repeatable non-destructive examination data of LOFT ASME Code Class 1 welds to support LOFT in-service inspections for thick austenitic stainless steels.

Prime Objectives

The LOFT AUT program has six prime objectives.

(1) Perform required ASME Code Section XI volumetric examinations with AUT techniques for ASME Code Class 1 piping.

(2) Perform LOFT in-service inspection examinations at a maximized rate using one basic AUT system with minimal plant downtime.

(3) Perform LOFT in-service inspection examinations with minimal radiation exposure to personnel.

(4) Provide significant improvement in flaw image characterization capability to satisfy the full intent of ASME Code Section XI in-service inspection requirements particularly in thick austenitic stainless steel sections. This objective includes improvement in the capability to discriminate between false and real indications.

(5) Re-establish the manually obtained ultrasonic baseline examination results of the LOFT ASME Code Class 1 welds using AUT to support the LOFT in-service inspection examinations.

(6) Develop and evaluate a field usable AUT system based on the laboratory developed system.

Advantages and Limitations of the LOFT AUT System

The system possesses four advantages over conventional nondestructive test techniques. First, the system provides permanent, retrievable, repeatable records not available with conventional nondestructive volumetric examination techniques. Second, the system significantly improves data analysis capability by providing better image interpretation and flaw indication definition and by providing a rigorous method of data analysis. Third, the system reduces exposure of operating personnel to radiological and thermal hazards. Fourth, the system utilizes existing skilled technicians while improving the flaw indication characterization capability.

When compared to conventional nondestructive test techniques, the system possesses two limitations. First, system procurement and development and software development require lengthy lead times. Second, the initial system development costs are high, although replacement costs at the end of development will have decreased to approximately one-half the development costs for the initial LOFT system hardware.

Operating Experience

All of the previously stated prime objectives have been completely or partially satisfied. This has been accomplished by performing axial shear-wave, circumferential shear wave, and longitudinal wave examinations of 45 LOFT ASME Code Class 1 welds in 316 stainless steel pipes. Since the LOFT Facility is a very compact system, access to these welds was often restricted by wireways, components, and branch connections, often making the LOFT conventional and AUT examinations difficult.

Field trial examinations of LOFT have been performed for three years. In 1977, the trials emphasized the development of the electronic and computer hardware system while examining 16 LOFT ASME Code Class 1 welds. In 1978, the trials emphasized development of mechanical search head equipment while examining 13 LOFT ASME Code Class 1 welds. Hardware, procedural, and software changes resulted from these trials. In 1979, the trials emphasized the data acquisition and control software along with improvement of the examination and calibration procedures while examining 16 LOFT ASME Code Class 1 welds.

The types of indications detected with the system include weld root, laminal, poor fusion, slag, and crack indications. Five ASME Code reportable indications have been detected. Three of the five had already been detected by conventional ultrasonic methods while two of the five were discovered by AUT methods.

Several of the detected indications would not have been detected ultrasonically had the calibrations and evaluations been performed by Section XI rules. The ultrasonic isoamplitude diagrams generated by the AUT system were obtained at approximately 18 dB more sensitivity than required by Section XI.

Several problems were encountered while performing the examinations. The cabling system between the control console and the search wheel was discovered to be susceptible to damage. This resulted in loss of control of the search wheel. Consequently, the entire cabling system was replaced. In addition, infrared light-beam limit switches were incorporated into the search wheel to minimize the consequences of loss of wheel control.

A second problem involved the software. The original system software was found to be severely limiting. Therefore, it was rewritten to improve system utilization.

A third problem involved the data disc and tape system. The original system did not possess ample storage capability which limited the capacity for data handling. Consequently, these systems were expanded to improve the capability.

A fourth problem involved the calibration procedures. They were revised to improve their reliability and reproducibility.

The system has been converted to a field usable mobile system contained in a trailer that can be transported to the exterior of a reactor containment. The cables are routed to the pipe-mounted search head from the trailer outside containment. The mobile system has been successfully used for LOFT AUT examinations.

Future Work Scope

Efforts on the system next year will fall in the areas of qualification test development, system component improvement, and technology transfer.

The qualification test development will develop calibration standardization procedures and examination procedures per ASME Code Section XI rules. These procedures will be incorporated into the LOFT inservice inspection program.

Improvements of components will include minor modifications to the search wheel suspension system to ensure that the misalignment of the reference plane of the search wheel with the pipe axis will be minimized. The cabling and connector arrangements will be modified to improve reliability and ease of installation. A high speed analog-to-digital converter will be installed to increase examination speed. A large disc memory system and a gray scale display system will be incorporated into the system to improve the software capability and imaging capability. Search heads also will be developed to inspect double curvature surfaces on such components as pipe sweep-o-lets and valve bodies, to inspect smaller (10 to 20 cm) pipes, and to inspect steam generator nozzles.

The effort for technology transfer will involve quality engineers in the development of the qualification tests and will train quality assurance inspectors to use the system to perform LOFT AUT examinations. This effort will lead to the turnover of the system to LOFT quality assurance personnel for full system usage.

During the above efforts, LOFT ASME Code Class 1 welds will continue to be examined.

CONCLUSIONS

The LOFT AUT system has been developed to permit significantly improved image interpretation capabilities over existing ultrasonic methods by providing continually repeatable data acquisition functions. By virtue of the repeatable data acquisitional storage capability, the system has permitted flaw indication characterization to be more rigorously defined than conventional manual ultrasonic techniques. The field usable system has been used to perform examinations of ASME Code Class 1 welds on the LOFT primary coolant system as part of the LOFT inservice inspection program into which the AUT system will be completely integrated in the near future.

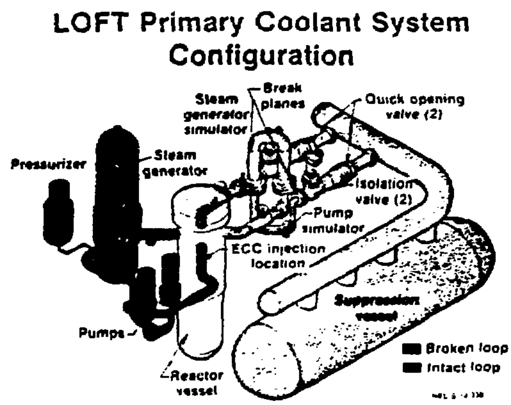

Figure 1. LOFT Primary Coolant System.

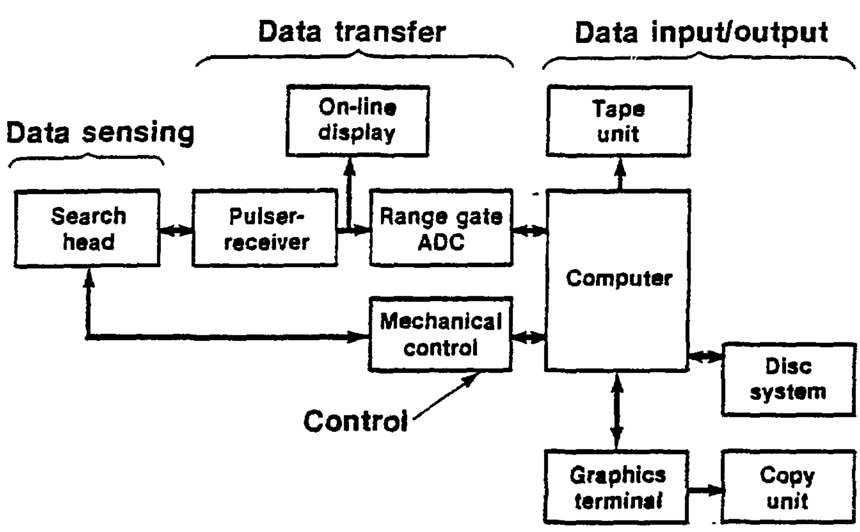

Figure 2. AUT System function diagram.

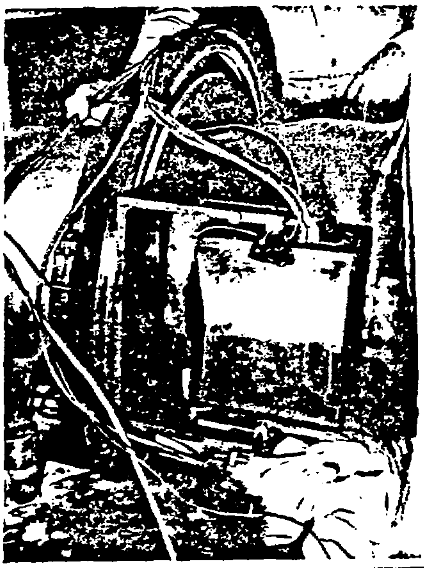

Figure 3. Search head installation.

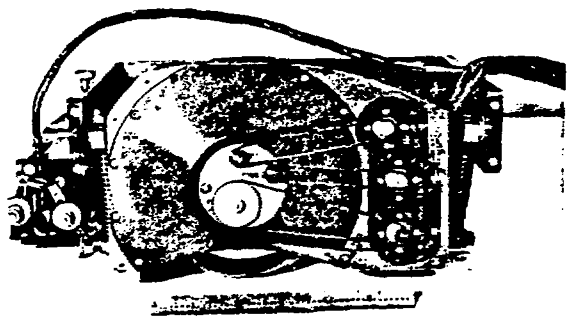

Figure 4. Search head drive system.

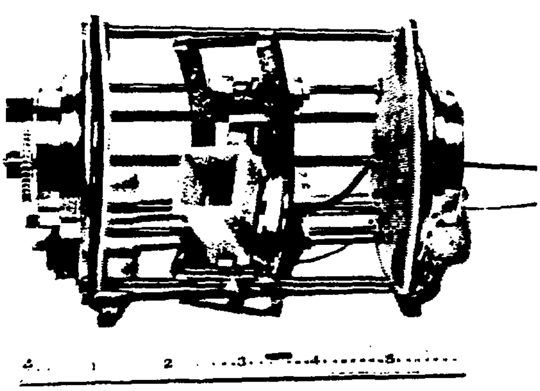

Figure 5. Search wheel internal configuration.