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Frontiers in NDE research nearing maturity for exploitation to ensure structural integrity of pressure retaining components

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Abstract

In this paper, research and developmental efforts that demonstrate high sensitivity detection and characterization of defects and assessment of microstructural degradation, residual stresses and fatigue damage in materials using different non-destructive evaluation (NDE) techniques, have been discussed. Applications of eddy current techniques for quantitative defect characterization and for generalized applications, and remote field eddy current technique for inspection of steam generator and heat exchanger tubes have been discussed. Advanced ultrasonic methods such as time of flight diffraction, synthetic aperture focusing technique, phased array and signal processing for detection, characterization and imaging of defects have been discussed. Applications of ultrasonics and magnetic Barkhausen emission techniques for characterization of microstructures and residual stresses have been discussed. Applications of acoustic emission and infrared thermography techniques for weld quality evaluation of critical nuclear components as part of intelligent processing of materials (IPM) work have been discussed. Application of acoustic emission technique for integrity assessment of pressurized components has been discussed. Development of a software called assets and infrastructure management system (AIMS), for storing and retrieving information for various materials, components and systems, has also been highlighted. The techniques and applications discussed are result of systematic and innovative R&D efforts in the multidisciplinary areas of physics, materials, instrumentation, sensors and softwares for providing solutions to various challenging problems.

Keywords: Non-destructive examination; Eddy current impedance; Remote field eddy current; Ultrasonic velocity measurements; Magnetic Barkhausen noise analysis; Acoustic emission and intelligent welding

1. Introduction

Pressure retaining components are fabricated to meet stringent design specifications with respect to fabrication quality and in-service performance. Important pressure retaining components are pressure vessels, pipelines, storage tanks, boiler drums, boiler tubing, headers, superheaters, reheaters, economizers, etc. These components are subjected to complex service environment such as exposure to elevated temperature, hostile media and loading. The adverse synergy of manufacturing realities and service environment (normal and off-normal) leads to degradation in mechanical properties of materials like strength, fracture toughness, etc. due to microstructural changes, corrosion, creep and fatigue damage. The successful performance of these components during entire life requires comprehensive implementation of a dedicated programme for stringent quality control during fabrication and condition assessment through on-line and periodic in-service inspection (ISI), coupled with mechanistic assessments and structural analysis. The condition assessment and life prediction approaches enable uninterrupted safe operation, avoidance of unplanned shutdowns and taking decision on repair, upgradation, modernization and replacement of necessary components for extension of the life of plants beyond their design lives. A key role is played through meticulous planning and incorporation of non-destructive evaluation (NDE) techniques which aim at detection and characterization of defects and evaluation of residual stresses, corrosion, microstructural degradations and dimensional changes that occur in components during their service life, due to exposure to high temperature, pressure, static and dynamic loads, hostile environment, etc.

Advanced NDE sensors, techniques, procedures and softwares are applied to meet stringent quality and in-service performance requirements of materials and components. Research in this field has been undertaken to gain in-depth understanding of interaction of probing medium with material through multidisciplinary bench mark experiments, and innovative analysis for characterization of defects and

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microstructural degradation of materials with high sensitivity and reliability.

In this paper, a few of the research and developments that demonstrate the usefulness of synergy between systematic and innovative approaches and sound knowledge in the multi-disciplinary areas of physics, materials, instrumentation, sensors and softwares in providing effective solution to challenging problems, are given. The specific topics discussed include advanced eddy current impedance imaging for defect evaluation, remote field eddy current systems for inspection of steam generator and heat exchanger tubes, ultrasonic and magnetic Barkhausen analyses for characterization of microstructures and residual stresses, and intelligent welding for obtaining reliable quality components and systems. After discussing these emerging developments, a few activities of significance towards quality control and in-service performance assessment of pressure retaining equipment are also highlighted.

2. Advanced eddy current impedance imaging for defect evaluation

For detection and characterisation of defects in components made of metallic materials, eddy current testing is widely preferred in view its versatility, reliability and speed. Conventional eddy current testing methods involve obtaining impedance change information as a function of scan distance and analysing eddy current signal thus formed to determine unique signal parameters such as peak-to-peak amplitude and phase angle for quantitative evaluation of defect dimensions. However, most of these methodologies have been found to be operator dependent and subjective. In this regard, there are many advantages one derives by resorting to digital instruments and digital signal processing methods. With the availability of powerful and less-expensive computers and data acquisition/interfacing cards, the face of eddy current testing has changed. In the case of analogue instruments, the analogue signals from eddy current instruments are digitised using data acquisition cards for applying digital signal processing methods to generate input data for quantitative evaluation modules. A significant progress has been made in the recent years in the area of digital eddy current testing. Realisation of an intelligent imaging with data fusion for automated eddy current testing of metallic plates is one such example that involves synergistic use of artificial neural networks, raster-scan imaging techniques and image processing methods and the same is discussed in the following sections.

2.1. Intelligent imaging with data fusion

Automated detection and characterization of defect or discontinuity in components both during manufacturing as well as during service life is gaining importance and interestingly, majority of NDE techniques are amenable for automation. The basic advantage of automation is near-total elimination of operator induced errors and possibility for NDE data storage, analysis and archiving. Essential requirement for automated NDE is scanning NDE sensor in pre-defined manner to cover the region of interest and processing the acquired information to make a decision on the presence of a defect or discontinuity. However, planned scanning of a sensor over component surface gives additional benefits. To site an example, by raster-scanning an eddy current sensor over a metallic plate and acquiring and displaying impedance data, eddy current images can be formed. Such images represent complete information about the extent of discontinuities in two dimensions. Working in this direction, an eddy current imaging system has been developed in-house and eddy current images of fatigue cracks, notches and corrosion pits, etc. have been generated. The spatial information of defects has been obtained from the image data and correlated with the actual dimensions of the defects. It has been established that imaging techniques enhance the probability of detection. However, images have been found blurred due to the convolution effects of finite-sized sensor. In order to restore the blurred images for obtaining accurate size of defects, a variety of image processing methodologies involving deconvolution and wiener filters have been developed.

Besides blurring, eddy current images are influenced by disturbing variables such as variations in material properties, surface roughness, lift-off, edge-effect, etc. In order to detect and characterise defects in the presence of these disturbing variables, a new intelligent imaging scheme has been developed and this has been successfully tested on austenitic stainless steel plates and welds [1,2]. This scheme breaks down the overall problem into two viz. detection and characterisation. This scheme quickly detects defects in the presence of disturbing variables in the first stage, through a coarse raster-scan and then produces accurate three-dimensional pictures of the detected defects in the second stage, through a fine raster-scan. The important step in this fine scan imaging is fusion of images processed through two different routes. The coarse and fine scan imaging stages are accomplished through the synergistic use of artificial neural networks and image processing methods. In order to realise quick and on-line detection and accurate depth evaluation of defects in the presence of the disturbing variables, a three-layer feed forward error back-propagation neural network with 12 input nodes (EC time-domain parameters from two frequencies), five hidden nodes, and one output node (defect depth in millimetre) has been developed. The EC probe for imaging has been optimised using an indigenously developed finite element model. The intelligent imaging scheme as illustrated in Fig. 1 involves the following steps:

- imaging of pre-defined region at a coarse scan interval (ΔS) using a neural network trained with linear and circular defects for mere defect detection purpose,
- automatic identification of boundaries of all defects using an image processing method called chain-code,
- identification of defect shape using the aspect ratio (>2 linear, <2 circular),
- imaging only the defective regions at a fine scan interval using separate neural networks for accurate depth quantification of linear and circular defects,
- applying the image processing approach to fine-scan depth-profile images for accurate restoration of length, width and orientation of the defects,