INSERVICE INSPECTION OF CLADDING USING PHASED ARRAY ULTRASONIC TESTING SYSTEM

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Abstract: *Cladding is process of coating of low alloy base with high alloy overlay to safeguard the base metal from corrosive fluids and fumes. Conventional ultrasonic testing is used to detect flaws in cladding and to enhance the quality of the product during the manufacturing stage. When the component is put to operation, miniscule flaws could propagate due to high working temperatures and pressures thereby reducing the service life of the product. Process plants and nuclear power plants undergo periodic in-service inspection to verify the integrity of components using NDE technique. Conventional ultrasonic testing is limited in application and Phased array ultrasonic testing (PAUT) as an advanced NDE technique could be a viable alternative. This paper details about the application of PAUT to detect a variety of bonding layer flaws in in-service inspection of cladded components.*

Keywords: *Cladding, NDE, UT, PAUT*

1. INTRODUCTION

Corrosive surfaces on valves, pipes, shells, tube sheets are often coated with high alloy deposit to safeguard the parent metal from corrosive acids and gases. This process of cladding is widely used for coating equipment in pressurized corrosive environment[1]. Clad alloys are generally nickel chromium based alloys which are well known for its creep and corrosion resistance properties. The various means of depositing clad metal over the parent metal are by roll bonding, explosive cladding and weld overlaying. Weld overlaying is the most popular and versatile form of cladding employed in a wide range of industries[2].

Ascertaining the soundness of the cladded joint is important in ensuring the service life and safety of the component. Unsound welding practices would result in a variety of longitudinal and planar flaws[3] in the volume of cladding. Prominent flaws which weaken the bonding between clad and parent metal are lack of fusion and under clad cracks. These flaws can propagate during the service life of the component and pose a serious threat to the safe operation of the equipment[4]. There is a need to monitor the origination of such discontinuities and propagation of existing miniscule discontinuities during the service life of the equipment. In-service inspection and shutdown maintenance are periodically carried out to assess the integrity of the cladding.

To test the integrity of the cladding, presently Non Destructive Examination techniques such as Dye penetrant testing[5] and Ultrasonic testing are being used. Dye penetrant testing detects flaws open to the surface only. Access to cladding surface is required to carry out dye penetrant testing. Most of the cladded portions are inside diameters of pipes, shells and tube sheets where access to cladded surface is limited. Thus dye penetrant examination is not a feasible NDE technique to test cladding during in-service inspection.

1.1 Ultrasonic Testing

Ultrasonic testing has been the most reliable NDE technique to detect flaws in the volume of the clad metal and clad- parent metal interface[6] when testing is carried out from the cladding surface. Ultrasonic testing system typically consists of a pulser which generates high voltage electric pulses. Driven by pulser, transducer generates high energy ultrasound. The ultrasound is propagated through the cladding from the cladding surface. When the ultrasound encounters a discontinuity, it is reflected back and received by the transducer. The received ultrasound is recorded as an echo or blip on the cathode ray oscilloscope screen. Ultrasound signal travel time is directly linked to the distance covered by the sound wave in the material. This information is deciphered to deduce the flaw location, size, orientation and other features[7]. In simple conventional UT machines A-scan is the common form of representation of the flaw on the UT screen as shown in Fig 1. A-scan presentation displays the amount of reflected ultrasound as a function of beam travel distance. The received energy is plotted along vertical axis as a percentage of full screen height. In ultrasonic testing carried out conventionally, a single probe is capable of generating ultrasound only at a specific angle in the work piece. Flaws which are perpendicular to the direction of ultrasound can be easily detected. Ultrasonic testing in in-service inspection of cladding is limited due to inherent attenuation difference between the parent metal and cladding. A new approach is required to carry out testing of cladding during in-service inspection to monitor the propagation of flaws. Phased array is an advanced NDE technique which is successfully used in the testing of welds and forgings. It has the potential to be applied in in-service inspection of cladding.

Fig 1. A- scan Presentation of Flaw Detection in Conventional UT

1.2 Phased Array Ultrasonic Testing

Phased array ultrasonic testing uses a phased array transducer which is essentially a large single-element transducer whose active area has been subdivided into small segments or elements. When connected to a phased array instrument, the direction and focus of the sound beam can be changed on each pulse repetition by pulsing individual elements at slightly different times or in different order. Phased Array also lowers the probability of missing flaws due to operator error. The most characteristic aspect of Phased Array Ultrasonic testing is beam steering and beam focusing (Fig 2 and Fig 3). In a single static position of the probe, multitude of angles can be generated [8]. Ultrasound can also be focused at the cladding interface by passing through the parent metal for accurate results. In Phased array UT, multitude of ultrasound beams are generated at various angles in the test specimen. The probability of detection of flaws oriented at different directions is enhanced. Data from phased array scan can be simultaneously represented in the form of A- scan, B- scan, C- scan and S- scan as shown in Fig 4. B-scan is a simple collection of A- scans. In B-scan, beam travel path of the sound beam is plotted against the position of the transducer in a line scan. C-scan presentation gives a plan-type view of the location and size of test specimen features. S scan gives a sweep view of the ultrasound beam. Thus multiple information can be obtained from a single phased array scan. Scan data can be encoded against the position of the probe. An encoder scan collects

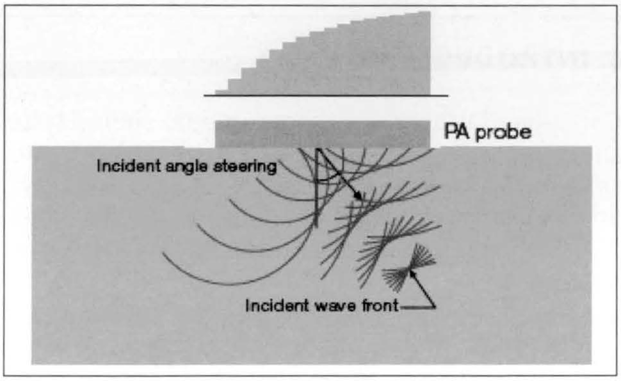

Fig 2. Beam Steering Capability of Phased Array System

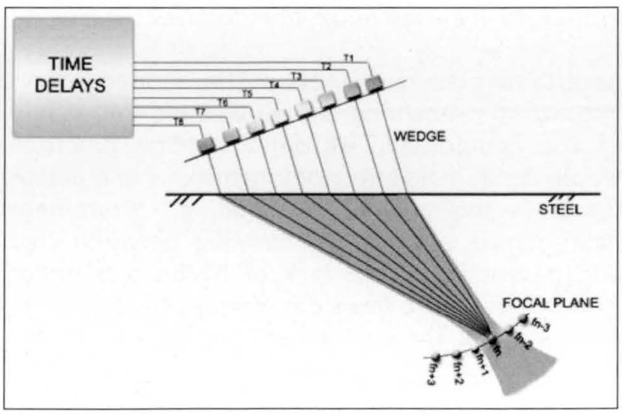

Fig 3. Beam Focusing Capability of Phased Array System

Fig 4. Phased Array Ultrasonic Testing Equipment with A, S and C Scan

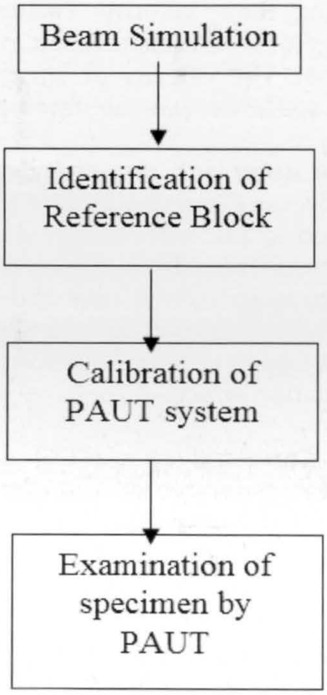

Fig 5. Flowchart for Carrying Out Experimentation

the entire waveform data to give information on flaw orientation and severity [9]. Encoder scan data is stored which can be used to analyze and characterize the flaw. Encoder scans are less operator dependent and the experience of the operator is not as critical as in UT. Encoded data can also be analyzed with a separate analyzing software at a convenient time.

2. APPLICATION OF PAUT

To plan a Phased Array test (Fig 5), Beam modelling and simulation serves an effective way to determine the optimum test parameters. Simulation aids in selection of transducers and evaluation of beam patterns generated by the transducer. Beam tracing software such as ES Beam tool provides an innovative approach to phased array linear and sectorial scanning by determining weld volume coverage in each scan.

A reference block with standard size induced flaws serves as a reference standard for sizing of discontinuities in the specimen.

PAUT equipment is calibrated using the reference block.

Inconel alloy 600 cladding over 20MnMoNi55 steel serves as a test specimen. Examination of the specimen is carried out using data derived from the beam tracing software.

The result of the tests are scan images which are analyzed and compared with that of traditional UT technique.

2.1 Beam Simulation

The test specimen of required dimensions and desired material properties can be simulated in the ES Beam tool software. Scan area coverage and overlap between subsequent scans can be established using this software as shown in Fig 6. Along with probe and wedge parameters, focal law detail need to be fed into the Phased array system. Focal laws determine the beam focusing and steering characteristics of the probe. From the evaluation of beam simulation carried out using ES Beam tool, optimum number of scans

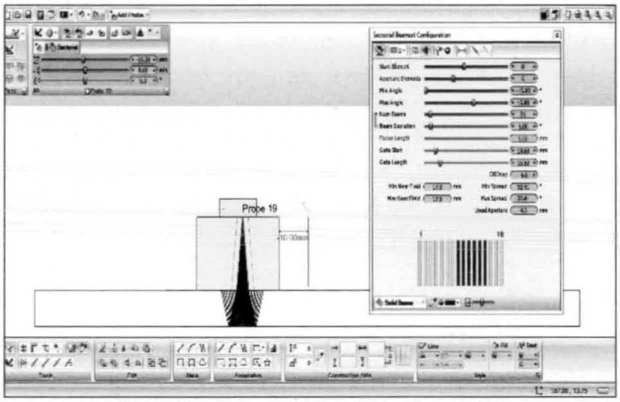

Fig 6. Phased Array Ultrasound Beam Simulation Using ESBeam Tool

Table 1: Probe and Wedge Characteristics for the Experiment

Total number of elements	64
Element quantity for generating ultrasound	8
First element to be used for scan	1
Focus depth	30 mm
Angle of inspection	-15 to +15 degree
Angle step	1 degree

Table 2: Phased Array Transducer Data

No of elements	64
Frequency	5 MHz
Pitch	0.6 mm
Active aperture	4.8 mm
Wave	Longitudinal
Wedge dimensions(L*W*H)	58*20*23 mm
Nominal refracted beam angle in steel	0°

to cover the entire cladding volume was chosen. The probe and wedge parameters employed are indicated in Table 1 and Table 2.

2.2 Reference Block

Reference reflection is set against reflection obtained from a standard reflector. Normally side drilled holes are used as a reference reflector in PAUT. To detect flaws at the interface between clad and parent metal, side drilled hole of diameter 1.5mm is drilled at the interface for a depth of 20 mm as per the requirements of American Society of Mechanical Engineers (ASME) standard section V as shown in Fig 7. The parent metal thickness of the reference block should be comparable to that of actual pressure vessel parent metal thickness.

2.3 Calibration

Three types of Calibration are required to be carried out with PAUT equipment-Velocity, wedge delay and Time Controlled gain calibration. Using the standard reference reflectors in the reference block the following calibrations were carried out.

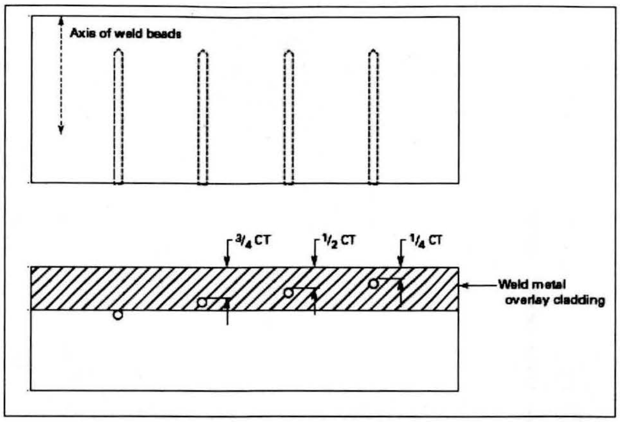

Fig 7. Reference Block as per ASME Sec V Edition 2015

2.3.1 Velocity calibration – As the ultrasound passes through two different attenuating materials - 20MnMoNi55 and Inconel cladding, the velocity calibrated is an average of velocities travelled in each of the material. The velocity of ultrasound beam in the specimen was calibrated as 5875m/s.

2.3.2 Wedge delay and sensitivity calibration – All individual beams (-15 to +15 degree) to be used in the examination was calibrated to provide measurement of distance and amplitude correction over the sound path employed inclusive of compensation of wedge sound path attenuations and wedge attenuation effects.

2.3.3 Time Corrected gain (TCG) calibration - TCG was generated at multiple points over all defined focal laws. This allows the use of sizing curves at multiple angles for sectorial scans.

2.4 Examination by PAUT

Encoder scan is employed in carrying out PAUT examination as the system records data against the motion of the probe in a line scan. Overlap between subsequent scans was deduced as 15 mm from ES Beam tool modelling. Line scanning was carried out along the length and breadth of the specimen. The resultant data is displayed on the screen as A, S, C scan. Flaw indications are color coded. Discontinuities exceeding the reference limit of 1.5 mm side drilled hole are in bright red color. Yellow and blue designates discontinuity indications less than 1.5 mm side drilled hole in that order.

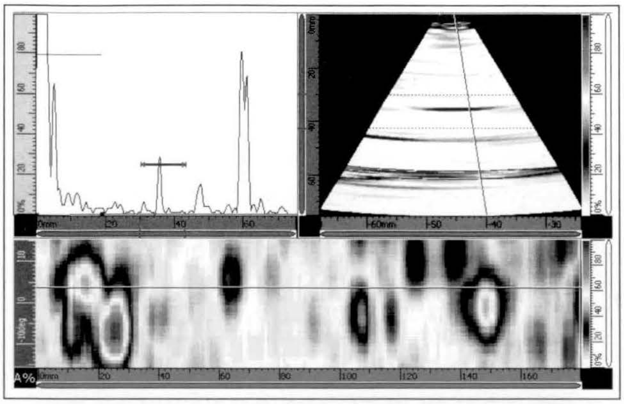

Fig 8. Linear Scan PAUT Images of Flaw 1 Which Was Not Picked up by Conventional UT

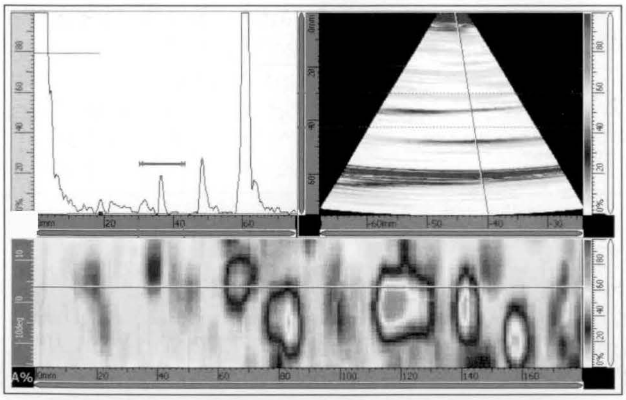

Fig 9. Linear Scan PAUT Images of Flaw 2 Which Was Not Picked up by Conventional UT

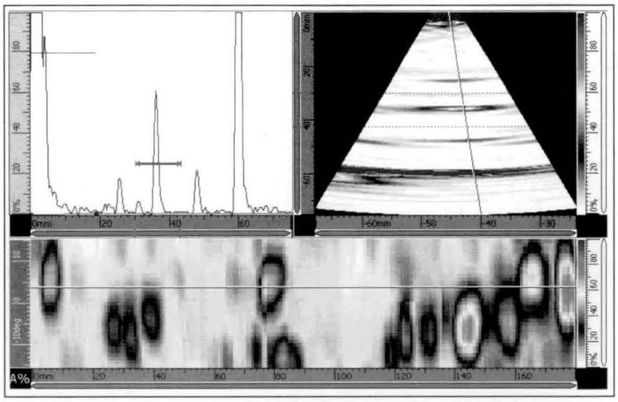

Fig 10. Linear Scan PAUT Images of Flaw 3 Which Was Not Picked up by Conventional UT

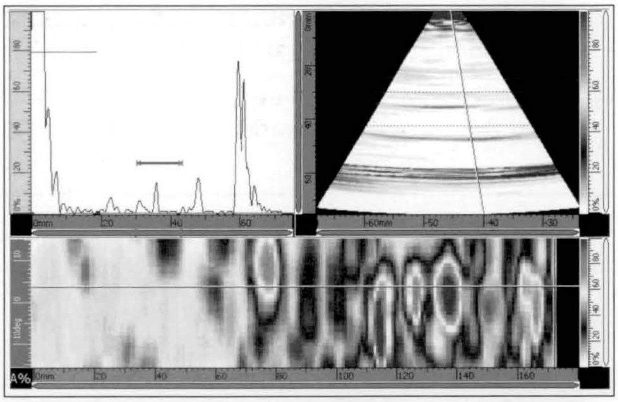

Fig 11. Linear scan PAUT Images of Flaw 4 Which Was Not Picked up by Conventional UT

3. COMPARATIVE STUDY

The results of PAUT are available in easily readable jpeg format. The images in Fig 8, 9, 10, 11 shows internal discontinuities of the specimen in A, S, C scan in PAUT. PAUT has detected four flaws with severity greater than 1.5 mm side drilled hole. Conventional UT failed to detect these flaws. PAUT has detected these flaws owing to its beam steering and focusing ability. On analysis of the A scans of the scan images, the flaws were deciphered as cracks. Early detection of cracks during in-service inspection serves to monitor its growth and rectify the same when necessary.

4. CONCLUSION

This paper details the applicability of PAUT to testing of cladding in pressure vessels during in-service inspection. It offers flexibility to carry out testing from parent metal side as testing from cladding surface is not possible. It establishes that UT is limited in application for in-service inspection of cladding.

PAUT offers following significant advantages over UT.

1. Beam steering at optimum angles to improve probability of detection of flaws.
2. Beam focusing allows optimization of the beam shape and size at the flaw location.
3. Electronic scanning permits rapid coverage of cladding volume.
4. Better defect detection and sizing.

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"Hard work doesn't guarantee success, but improves its chances"

- B J Gupta