UNDERPINNING PLANT CONDITION AND INTEGRITY BY SPECIALISED NDE INSPECTIONS

J Costain
RWE Innogy plc, Swindon, UK

Abstract: During the last fifteen years, the power generation industry in the UK has undergone considerable change, evolving from a single state owned company to a collection of individual power plant owners. As a result of this, research and development activities in Non-Destructive Examination have become commercially focussed and the need for improved and innovative techniques is even greater as operators seek to extend the life of plant and operate it with greater flexibility. Within this period standard automated ultrasonics and phased array ultrasonic technology has become one of the most prominent areas of development within Non-Destructive Examination providing a more accurate and efficient way of inspecting critical plant items.

This paper talks about the advances that RWE Innogy has made in Non-Destructive Examination by utilising both standard automated and phased array ultrasound technology for power station applications to improve accuracy, repeatability and integrity whilst reducing the overall inspection time. It will detail the technical challenges we have overcome during our six years experience of working with ultrasonic phased array technology by presenting a number of examples which include steam turbine disc head inspections and the inspection of thick walled components such as steam chests.

Phased array has rapidly become a useful tool for the inspection of critical plant however there are still challenges ahead for industry to accept the new technique and to recognise the need for certified training.

Introduction: Historically, NDE inspections were considered to be routine and were often carried out by service inspection companies, however, in the past two decades, some areas of NDE have become increasingly more specialised and a different approach has had to be taken. Plant owners have demanded improved accuracy and repeatability and defect sizes that need to be detected have become progressively smaller. Specialised inspection techniques have been developed to engineer out human error, to provide permanent records, to maintain repeatability and to take into account the criticality of the plant. The cost of specialist NDE equipment has escalated, a single item can cost up to £100k. Whilst determining our inspection strategy, we have had to consider the availability of NDE services involving specialised inspection equipment, the cost of buying such services and the commitment and dedication provided by external suppliers. We have determined that no single supplier can provide the services we require, so in order to secure an effective competence, we have endeavoured to develop our own capability, using our own specialist inspection equipment and our own developed technology. The following paragraphs provide examples of how we have managed specialist inspection requirements, using dedicated equipment and bespoke techniques.

Phased Array Ultrasound: Phased array technology has been primarily developed in the medical field and in the last 7-8 years been adapted and utilised for industrial applications. This technology has provided significant improvements to standard ultrasonic inspections due to phased arrays inherent flexibility.

Although the physics of ultrasound and the generation of energy remains the same as standard single element piezo electric crystals the phased array technique enables the beam to be steered (azimuthal/sectorial scanning), electronic (linear) scanning and the ability to focus at different depths electronically.

In conjunction with advanced acquisition and analysis software the information that phased array techniques can provide the operator can increase the probability of detection and reduce false calls especially on complex geometries.

Turbine Inspections:

End Ring Inspections: A specialist NDE technique has been developed for the inspection of generator rotor coil binding rings (end rings) and may be applied to rings of compositions 8Mn 8Ni 4Cr, 18Mn 4Cr and 18Mn 18Cr. The technique is designed to inspect the end rings in-situ on the rotor and does not necessarily require the rotor to be removed from the stator (Fig. 3).

The technique has demonstrated an ability to detect axially aligned stress corrosion cracking as small as 1mm deep in susceptible materials. An end ring scanner capable of accurately manipulating the probe carrier in circumferential and axial directions on the end ring surface has been acquired, which is designed to access a 35mm air gap (Fig 1). The scanner (Fig. 2) has variable circumferential speed control in both circumferential directions and precise axial incrementing controls.

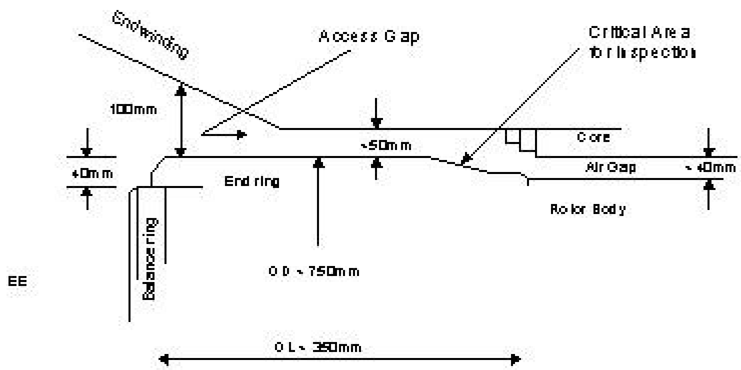


Fig 1 Rotor – Stator minimum measurements for in-situ

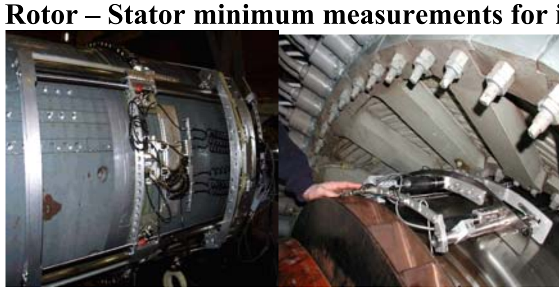


Fig 2 End ring scanner set-up & Fig 3 Inspection in-situ

The probe pans have been designed to house up to four probes, which may include angled, pulse echo and TOFD transducers. The probes are positioned circumferentially in line with each other with projected beams in opposite circumferential directions towards each other in a V path transmit-receive configuration. A means of remotely adjusting the circumferential distance between the probes has been arranged to obtain maximised transmit-receive responses on different thickness end rings. The probe housings are sprung loaded or pneumatically loaded and are designed to ensure adequate coupling between the probe and the end ring surface at all times. The end ring slope, which is a critical area for inspection has been an obstacle to in-situ inspections in the past but this developed technology and equipment have overcome that.

Rotor Bore Inspections: Many steam turbine rotors in service have hollow bores as they have been machined at the manufacturing stage to remove material of inferior mechanical and metallurgical properties from the central portion of the original forging. This has led to an unforeseen problem in that the thermal fatigue cycling which occurs during normal operation leads to the initiation of cracking from the bore surface which can lead to catastrophic failure in service. These internal bore surfaces are difficult to inspect, particularly with the level of flaw sensitivity required due to critical crack sizes involved.

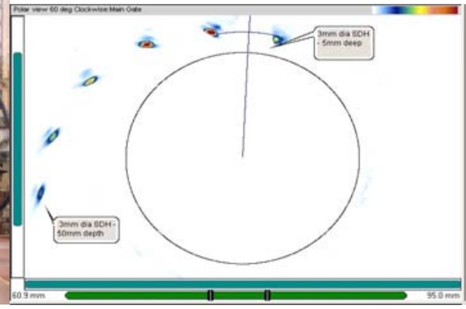
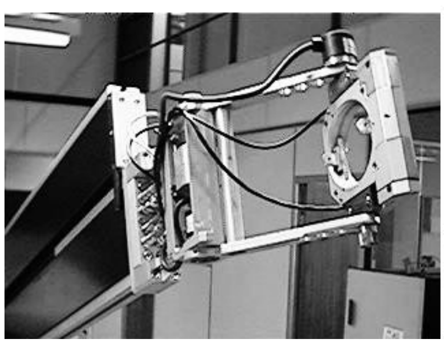


Fig 4 Rotor Bore Inspection System & Fig 5 – Volumetric Inspection – Polar View

The challenge has been to develop a high integrity rotor bore inspection system with high repeatability and flaw detection and sizing capability which can negotiate rotor bores of different diameters and lengths. In addition, to develop a system that will minimise inspection time, by simultaneous data acquisition for both volumetric and surface inspections.

The solution has been to develop an integrated system capable of volumetric and surface inspections of rotor bores of different diameters and changes of section, utilising ultrasonic and multiplexed eddy current probes scanning simultaneously. The scanning head moves on a helical path and the probes maintain contact with the bore surfaces by means of spring-loaded arms. The simultaneous encoded scanning allows data from both types of inspection to be displayed and reported using the same reference datum's. The powerful software also allows options for visualisation of information, i.e. in polar view and C-Scan format. Overall, savings of up to 60% can be realised in the time taken for the inspection when compared with separate ultrasonic and MPI/Visual inspections

Disc Bore Inspections: Certain LP rotors are susceptible to stress corrosion cracking, particularly at the rotor discs bores. It would incur considerable costs to remove the discs, for inspection and would likely result in disc/shaft damage. Techniques have been developed which specify the techniques, equipment and personnel required to carry out an ultrasonic inspection of LP rotor disc bore key-ways and bores to detect axial cracks. The axial extent of coverage along the key-way or disc bore is dependent on the particular disc geometry. The techniques involve the use of pulse echo and transmit receive ultrasonic methods, which are capable of detecting reference spark eroded slots 3 mm deep in disc bore key-ways and bores of LP rotor discs. The pulse echo techniques are primarily limited to the detection of defects and accurate sizing is achieved by the application of alternative techniques, such as time of flight diffraction (TOFD).



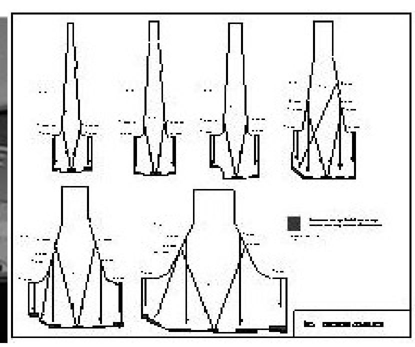


Fig 6 Inspection Manipulator & Fig 7 Multi angle inspection technique – probe requirements

In addition to the development of the techniques, specialised inspection equipment, the Disc Bore Inspection Manipulator (Fig. 6), has been purchased to accurately locate the probes for inspection. The manipulator also helps to cope with the ever-changing probe angle requirement (Fig. 7).

Curved Blade Roots and Steeples: Turbine blade roots and turbine rotor disk steeples can be susceptible to stress corrosion cracking from the hook positions. This particular inspection is challenging due to the complex structure of the components and due to the scanning surface which is not always conducive for standard ultrasound techniques.

To overcome the problem relating to the geometry a phased array technique has been developed using an azimuthal/sectorial scanning technique. This requires a beam to be swept over a number of angles with the probe being manipulated manually to ensure the beam is always orthogonal to the area of interest. In addition, the ability to produce a CAD overlay during acquisition provides further opportunities for the operator to distinguish between geometric indications and flaw indications.

Fig 8 and 9 – Curved blade root geometry

To develop the technique a standard validation process was followed which, included the modelling of the blade to enable sectioning at various points around the curvature. This enables the correct beam skewing to be calculated which changes around the blade section. As can be seen from fig 10 skewing of up to 20% is required in specific locations.

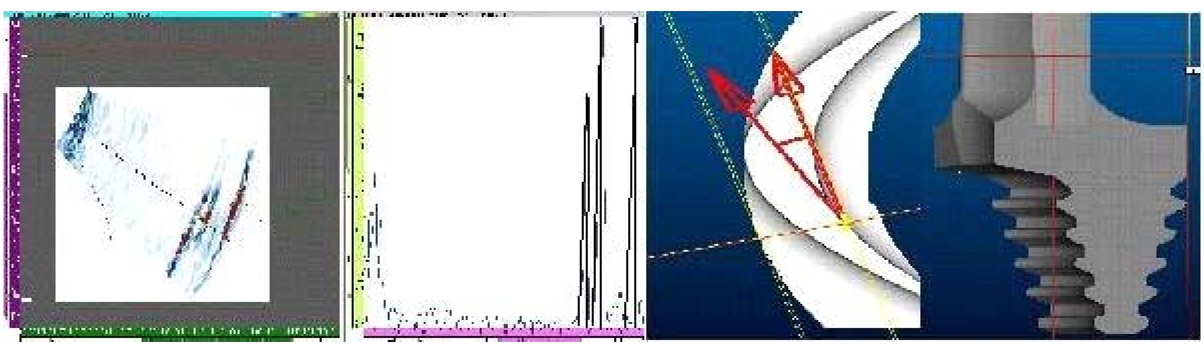


Fig 10 – Beaming skewing and typical phased array image

The results from this section are tabulated in fig 11 which show an excellent s/n ratio.

Defect ID	Datum	Probe ID	Frequency	Wedge ID	Angle	Defect db to FSH	1.5mm SDH to FSH
SH1N4	+190mm	5L16E16-10	5 MHz	PA42-002	61.0º	41	32
SH2N4	+180mm	5L16E16-10	5 MHz	PA42-002	69º	32	32

Fig 11 – typical defect results

From a practical scanning point as can be seen in fig 12 a manually manipulated scanning pattern has been determined as having the best probability of detection without the need for a multi-axis, very expensive and complicated dedicated manipulator.

Fig 12 – manually manipulated phased array technique

Scanning can be performed from the aerofoil and also from the root platform and using the phased array technique requires less accuracy than a single element probe.

Steam Chests: Steam chests are large low alloy castings which equalise steam pressure before entry into the turbine from the boilers, they are also equipped with ESV's, emergancy stop valves. Steam chests suffer from thermal fatigue cracks on the inside radii often caused when hot steam rushes from the boilers down the high pressure piping into the cold steam chest. The fatigue cracks have been known to turn into creep and failures can occur. The cracks can be detected quite easily using manual UT techniques but sizing due to long beam paths and external restrictions is very difficult. TOFD has been used quite successfully as a sizing tool but again due to large PCS and internal geometries, access and interpretation is difficult.

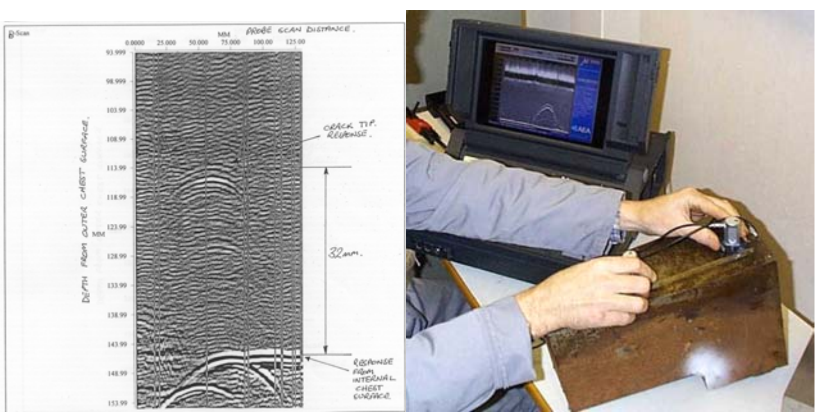


Fig 13 Typical TOFD result and TOFD in operation

A phased array technique has been successfully implemented to overcome the problem associated with TOFD and Pulse Echo. Only a small scanning area is needed for the inspection and with the imaging capabilities a clear view of the component geometry and crack existent and orientation is possible. Orientation is important as remaining wall will differ pending the crack direction.

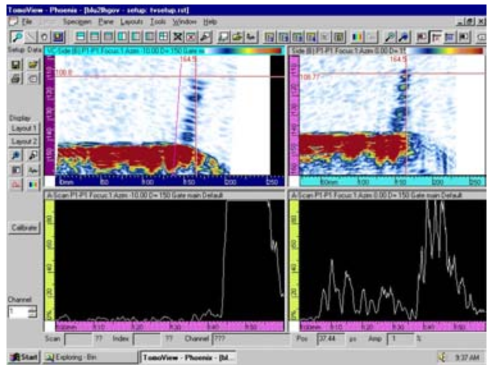
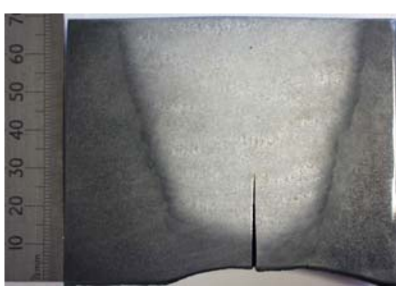


Fig 14 Phased array image of crack orientation

Pipework Inspections

Bore Cracking: During power station outages in 2001, cracks were detected in the bore of main steam pipework at a number of plants in the UK. These cracks (Fig. 15) were detected initially adjacent to boiler stop valves at the top of the boiler, but later were found further down the pipework legs. The cracks were first discovered during a full weld repair on a main steam butt weld that had been identified as containing Type IV cracking by primary NDE/replication. Whilst excavating the damaged material, the machining operation broke into the crack. The routine volumetric inspection of welds in high temperature/pressure steam pipework includes an ultrasonic survey of the root area for fabrication and in-service flaws. Sub-contract staff normally carries out these inspections, working to procedures provided by the owner or owner's representative and these inspections have failed to identify the defects. Innogy NDE engineers carried out an investigation specifically designed to look for root cracks. Sectioning and metallurgical examinations were also carried out. It became clear that the cracks were thermal fatigue cracks and were very straight, featureless (i.e. no facets) and oxide filled. They were also perpendicular to the bore and often multiple in number, being associated with changes of section such as counter-bores and weld roots.



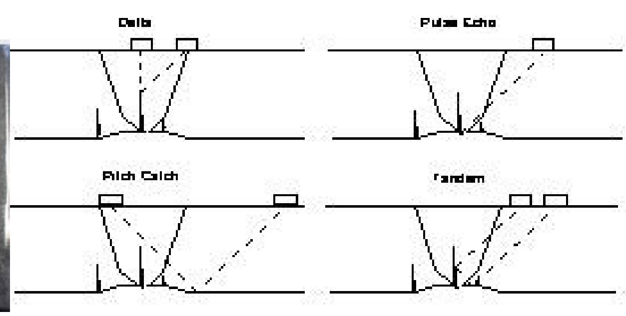


Fig 15 Severe Pipework Bore Crack & Fig 16 Ultrasonic NDE Techniques

These cracks are very difficult to size accurately by standard NDE applications. Experimental work has determined that a number of known techniques, such as Pulse Echo, Tandem, Delta and Pitch Catch (Fig. 16), are not capable of accurately sizing these cracks. Phased Array, TOFD and other advanced NDE techniques have also been investigated.

Further experimental work has determined that Time of Flight Diffraction (TOFD), together with advanced image capture utilising the Innogy pipe scanner, is the most reliable method of sizing bore-cracking defects (Figs. 17 and 18).

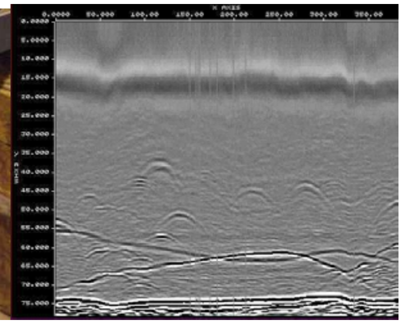
 

Fig 17 Innogy Pipe Scanner & Fig 18 TOFD Image - Two Bore Cracks

Dependant upon having good operational control, the bore cracks are considered to be relatively slow growing therefore it is not necessary to remove them below a certain size. Accurate sizing however, is essential if we are to monitor the progress of Bore Cracking, particularly when it reaches the point when creep will influence crack growth.

Conclusions: NDE is worthwhile and necessary if we are to gain essential knowledge of safety critical plant.
RWE Innogy continues to invest in equipment and advanced inspection techniques that give operations vital knowledge of plant condition and risk and allow informed decisions to be made regarding safe operation and economically advantageous component management.

Advanced NDE techniques do provide significant advantages in terms of probability of detection and the reduction of false calls. There are however serious considerations when applying such techniques which include operator training, procedure validation and applicable international codes and standards.

A good example of where new techniques have taken time to be accepted by the international community is Time of Flight Diffraction. Developed in the early 1970's to improve critical sizing of known cracks in reactor pressure vessels the technique has taken over 30 years to be accepted as a valid inspection tool. This is some what to do with the technique being "over sold" and only when the industry fully understood the limitations as well as the advantages could the technique be used to its full potential. The publication of the ASME code case 2235 has enabled TOFD to be used and referenced to an acceptable code and the introduction of a TOFD PCN operator qualification has also led the increased use of what is a valuable tool.

The same could be said for phased array ultrasound and it is important that the industry recognises the need for internationally recognised training and certification. In addition, the inspection companies and regulatory authorities need to fully accept that know one technique can be used in isolation and each has its benefits and limitations. Inspection design has to encompass the requirement to use a multi technique approach in many cases which will provide a fit for purpose examination.