PRACTICAL EXPERIENCE OF PHASED ARRAY TECHNOLOGY FOR POWER STATION APPLICATIONS

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Abstract: This paper talks about the advances that have been made in Non-Destructive Examination by utilising phased array 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 five years experience of working with ultrasonic phased array technology by presenting a number of examples which include steam turbine disc head inspections, curved blade root 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: During the last twenty 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. Funding for research and development activities in Non-Destructive Examination has now become commercially focussed; the accuracy, repeatability and the need for improved and innovative techniques is even greater as generators seek to extend the life of plant beyond design life whilst expecting it to be more flexible to compete in the current harsh commercial environment [(1)].

During this period, several new ultrasonic methods have been developed and matured into useful techniques including most prominently Time Of Flight Diffraction (TOFD), Electromagnetic Acoustic Transducers (EMATs), Guided Wave Ultrasonics, Acoustic Emission and Phased Array technology, some having a more torturous route to success than others. Success has only been possible by the co-opereration of universities, manufacturer and most importantly specialist NDE providers, who have realised the potential and justified the need for further investment in these techniques
on the basis of previous inspection successes. RWE Innogy has made several advances in many of the above techniques, but predominantly in the area of phased array technology whereby it can be demonstrated that its capital investments can reap benefits for the service provider and the client.

The following paragraphs provide examples of how we have employed phased array technology where is has been economically viable, demonstrating the benefits of investing in modern specialist equipment to improve defect detection and characterisation, accuracy and repeatability whilst engineering out human errors and providing hard copy results for off-line analysis and to help the client interpret the results.

Rotor disc inspections: Certain rotors are susceptible to inter-granular stress corrosion cracking, particularly at the rotor disc head. One would incur considerable costs to remove the blades for the inspection of the disc heads by surface techniques which could result in damage to the disc head arrangement. Historically manual single element ultrasonics has been employed where the cost of removing the blades proved uneconomical however there are several drawbacks with this technique. Firstly, the inspection is time consuming due to the repetitive rastering of the probe and because only one serration at a time can be inspected. Secondly, as the inspection is repetitive, it is highly probable that defects can be missed especially if the operator doesn't take sufficient breaks during the inspection. Automation would be of benefit to remove human error however, the manipulator would be complex to cope with the rastering of the probe in addition to moving the probe around the rotor.

Figure 1: Rotor disc head manipulator

The phased array technique developed follows the same principles as the manual technique except that the manual rastering of the probe is replaced with electronic rastering, therefore a simple manipulator can be employed (see figure 1) with the added benefit that the same manipulator can be used for the inspection of disc bores and blade roots. Electronic scanning can be either azimuthal (see figure 2), linear or a combination of both, allowing better defect detection and accessibility to the top serration. Furthermore, depending upon the disc head geometry, all serrations can be inspected on both sides with only one revolution of the rotor. CAD overlays of the disc head geometry can be added to the inspection file to aid the interpretation of the data and help explain the defects to the client (see figure 3). With the manipulator on a track parallel with the rotor, this allows the whole rotor train to be inspected without having to reset any parameters, reducing the inspection time to a fraction of the manual inspection.

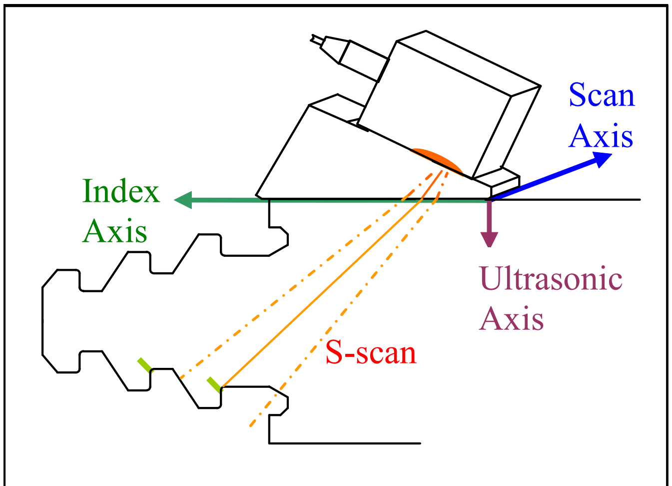

Figure 2: Azimuthal scan setup showing probe position on the disc head

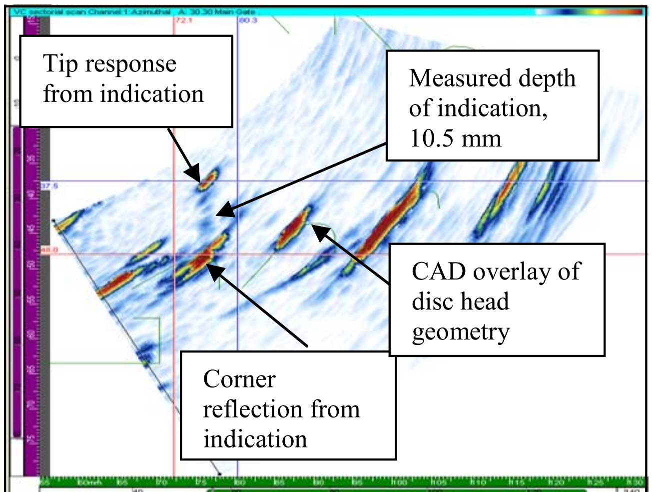

Figure 3: Azimuthal image of defective disc showing CAD overlay and defect sizing capability

Steam chest inspections: The function of a steam chest is to ensure the steam from the boiler is equalised in temperature and pressure before it is admitted to the turbine and also to provide a means of regulating the steam to the high pressure turbine for functional and safety reasons. Steam chests are thick walled components which suffer from fatigue cracks emanating from their inner radii due to temperature gradients throughout its bulk, present during startup and shut down. This problem has been accentuated in resent years by the need to two-shift the plant for commercial reasons. Steam chests were previously inspected using manual ultrasonics from the outside, and therefore beam paths of upwards of 200mm were encountered. This makes sizing of defects difficult as accuracies of +/- 2mm are required to ensure the defect has not grown between inspection intervals. The main problems in sizing at long beam paths are due to beam spread and the fact that the scanning surface may not be flat or parallel to the surface containing the defect. Time of flight diffraction (TOFD)
techniques have been introduced (see figure 4) to improve confidence in defect sizing, however this technique has one main drawback in that access to a large scanning surface is required. This is not always possible and furthermore, as there is no information on the orientation of the defect using TOFD, supplementary manual pulse-echo ultrasonics is still required.

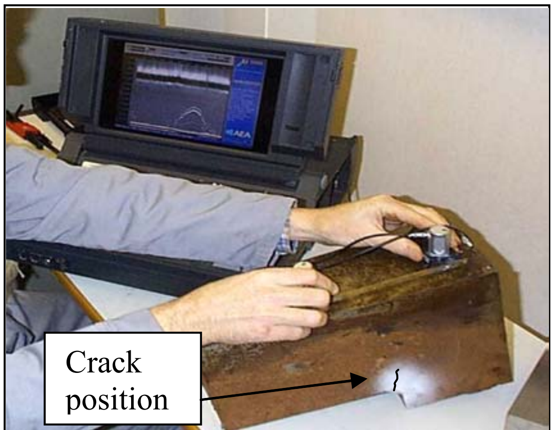

Figure 4: Tofd technique being employed on sample of steam chest

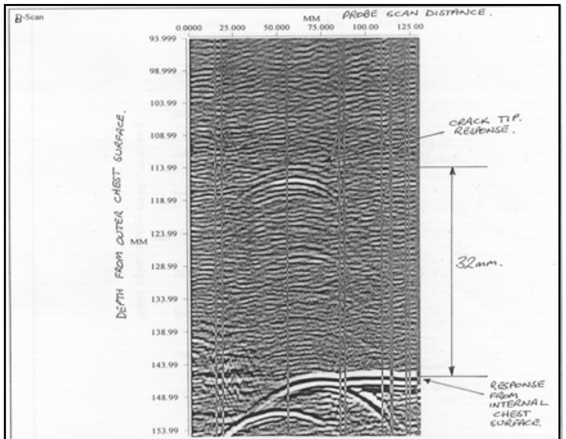

Figure 5: Tofd image form defect shown in figure 4

Phased Array technology solves both these problems. As with manual pulse-echo techniques, access is only required to one side of the defect, however, and as the beam can be swept through several angles simultaneously, this allows the inner surface containing the defect to be imaged at the same time as the whole crack face. This has two advantages; firstly, the technique can cope with irregular surfaces as the image of the defect and the inner surface move out of position together so by measuring the size of the crack relative to the inner surface, one always measures the true crack depth. Secondly, as the face of the crack is imaged, it is possible to determine the orientation of the defect (see figure 6). In addition, a CAD overlay can be used to aid client interpretation of the image.

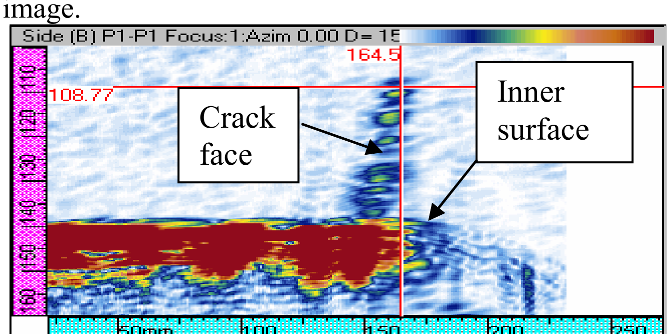

Figure 6: Phased array image of defect shown in figure 4 detailing crack size and orientation

Wedge bar inspections: Aluminium wedge bars are an integral part of the generator rotor, their function being to retain the copper windings positioned between the rotor teeth. Wedge bars are themselves located and held between the rotor teeth and run the length of the rotor, terminating underneath the retaining rings. Historically on certain types of rotors, wedge bars have exhibited cracking in the radii of the ears (see figure 7) where the wedge bar interfaces with the rotor teeth which have occasionally led to the catastrophic failure of the rotor. Subsequent metallurgical investigations have shown the failures were attributed to poor design of the wedge bars, giving a tight radius near the ears, effectively producing a stress raiser. This problem has been engineered out by modifying the wedge bars so that the radius is larger, however there is concern that cracking may still occur. To inspect the radius section of the bars, a manual shear wave pulse-echo technique was introduced whereby the operator rastered their probes across each wedge bar to interrogate the area of interest. The problem with this approach is that it is time consuming as there are in total over 100m of wedge bar to test and it is repetitive, so it is highly probable that defects can be missed especially when the defect size they are trying to detect are less than 0.25mm in depth. To further complicate the inspection, clients were requesting a hard copy of the results and that this inspection was to be carried out in-situ without removal of the rotor from the stator as rotor removal is prohibitively expensive.

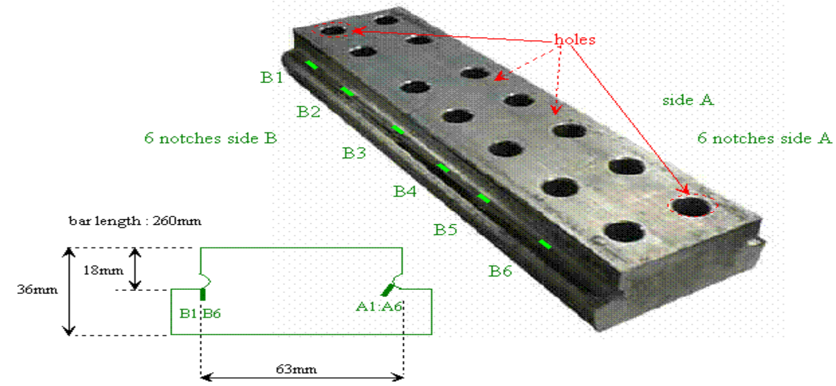

Figure 7: Typical wedge bar configuration containing artificial notches representing defects found in practice

An alternative phased array technique was developed (see figure 8) to overcome some of the problems with the manual technique. The phased array technique uses an azimuthal scan to replace the manual rastering of the probe enabling the technique to capture the information from the wedge bar using a simple line scan; ensuring 100% coverage. This allows the inspection to be carried out in a fraction of the time it took to manually inspect whilst producing a hard copy of the results. Furthermore, as the phased array beam can be focused at the defect location, defects smaller than 0.25mm in depth can be detected and sized if resolvable (see figure 9). The technique can also be automated using a simple one axis manipulator to inspect the bars with the rotor in-situ.

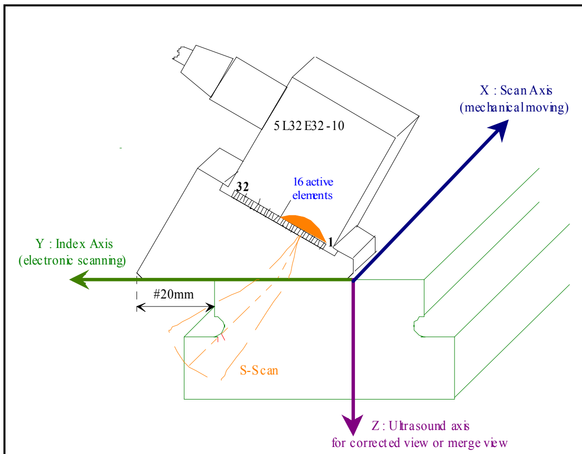

Figure 8: Probe configuration showing azimuthal scan pattern

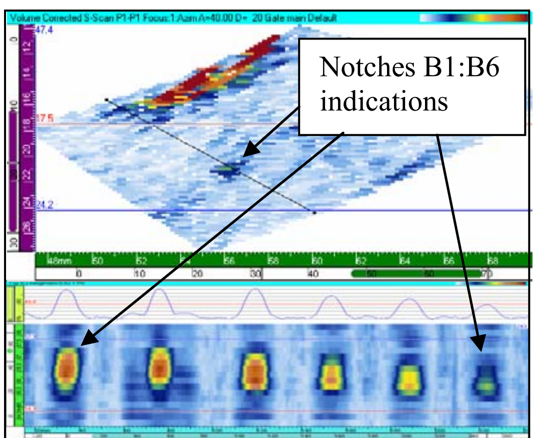

Figure 9: Results of initial validation exercise

Curved blade root serration inspection: As mentioned earlier, certain rotors are susceptible to inter-granular stress corrosion cracking, which can also affect turbine blades. As with disc head inspections, one would incur considerable costs in removing the blades for inspection using surface techniques. The added problem with blade root inspections without blade removal is that the inspection is complicated by the lack of simple inspection surfaces for ultrasonic investigation. With curved blade roots as opposed to straight roots the problem is intensified by the complexity of the ultrasonic scanning patterns which ideally must follow the line of the root serrations to avoid the necessity to skew the beam. Manual single element pulse-echo inspection of curved blade roots has been shown through experiment to be fraught with problems due to difficulty in understanding the data gained from manually probing over an ever changing geometry. A recent failure of a rotor caused by a cracked curved blade root has highlighted the need for regular inspection and an inspection technique capable of inspecting the blades while in-situ to reduce overhaul costs and duration.

Figure 10: Typical curved blade root configuration

Phased Array technology has shown to be a suitable alternative technique mainly because the probes can be positioned in areas whereby the use of azimuthal scanning allows the inspection to cope with ever changing geometries that would otherwise require several inspections with different single element angled probes. Therefore, the phased array inspections can be performed from the blade airfoil and other areas so that the area insonified can simultaneously distinguish geometric indications from the shape of the serrations and any possible flaws (see figure 11) allowing more flexibility as to where to position the probe for optimum coverage and defect detection. Validation work has shown that it is possible to inspect the whole length of the blade root serrations with improved confidence over the conventional single element technique (see figure 12).

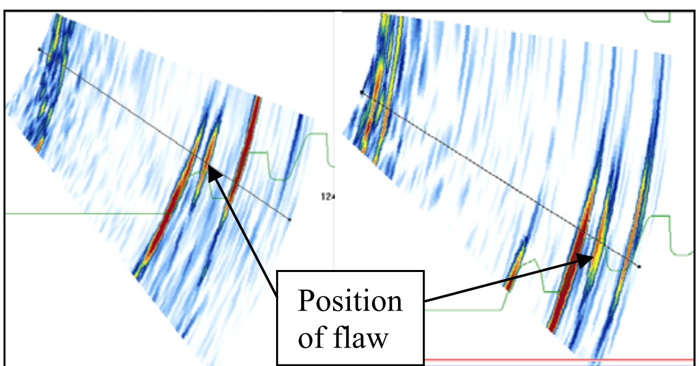

Figure 11: Phased array images showing flaws situated in top two serrations and CAD overlay (in green)

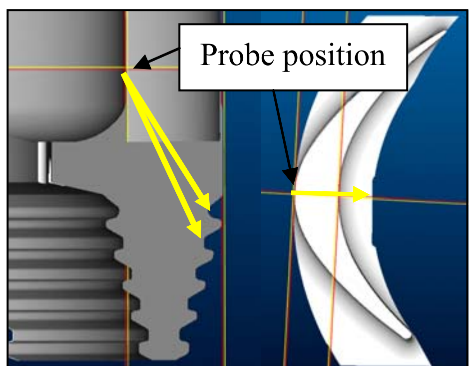

Figure 12: CAD image showing position of probes to produce images in figure 11

Conclusion: The benefits of using phased array technology had been demonstrated for a range different applications. In each case the inspection has benefited from one or more of the following:

- Reduced inspection time
- Hardcopy results which can incorporate CAD diagrams of components to aid visualisation of defects for clients
- Improved detection capability and critical sizing especially where component geometry is complex
- Improved repeatability and integrity
- Ability to position the probe with less accuracy (curved blade root inspection)
- Remove the need for fully automated techniques in certain circumstances by replacing rastering with electronic beam sweeping

Phased array technology is still in its infancy for industrial applications and will require further work to fully understand the benefits of the technology. In addition, thought must be given to producing standards and suitable training so that clients can be confident that the inspection will meet their needs.

Reference: 1. R. Lyon.,'Underpinning plant condition and integrity by specialised nde inspections,' EPRI/DOE – Conference on Advances in Life Assessment and Optimisation of Fossil Power Plants, March 2002