Detection of defects initiation in weld joints

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Abstract

Welded joints on various pipelines, especially steam pipelines of fossil power plants, are exposed to high pressure and temperature of steam during operation. The applied stress and temperature together with the chemical composition and microstructure of the material have a major influence on the damage growth in these joints. Growth of defects as a time-dependent event, the sensitivity of the material to damage due to stress temperature and others plays a major role. In the case of steam pipes of fossil power plants, this is mainly creep damage. Early detection of these defects, especially at their initial stage, can help in managing the service life and thereby reducing the costs for operation, both by minimizing unplanned shutdowns as well as by planning any repairs in time.

The work is focused on the detection of defect indications, especially creep damage occurring in weld joints and heat-affected areas. The aim is to distinguish manufacturing defects of welded joints from indications of early crack growth by ultrasonic testing. Indications from manufacturing defects may also be detected during testing and, if detected, will be evaluated in the same way as defects that are primarily targeted by the testing techniques. Several different techniques were tested on samples cut from the operated steam pipeline systems and compared with the results of metallographic analyses on selected parts.

KEYWORDS: Ultrasonic testing, creep, phased array, pipelines, weld joints

1. Introduction

Currently, the production of electricity still depends to a certain extent on the operation of energy units burning fossil fuels. Most of coal-fired units exceed several hundred thousand hours of service, which is beyond the original projected design life. This puts great demands on the individual components and especially on the performance of in-service inspections. For this reason, regular inspections are needed to ensure that all components are operated safely.

Early detection of service-induced defects in steam pipe welds, such as creep damage, helps to prevent damage that leads to rupture of the pipe walls during service.
Regarding the environment, especially the temperature ranging from 450 to 600 ºC, there is no simple applicable method of creep development detection. There are several methods that can bring us information that there is degradation of material in a given area and it is necessary to focus more on this place. These methods include, for example, 3D scanning, which, thanks to the detection of the degree of deformation, can determine places with possible development of damage or, possibly, the collection of replicas based on which it is possible to determine the stage of creep damage. In these critical areas, it is then possible to deploy volume methods that could detect defects that can lead to component damage or unplanned shutdown of the production unit. Very promising technique for detecting defects in early stage is phased array (PA) with using of additional advanced techniques such as Full matrix capture (FMC), Total focusing method (TFM) and Phase coherence imaging (PCI). Especially PCI seems very promising.

2. Advanced ultrasonic techniques

For detecting of small dimension defects several ultrasonic techniques were tested. Their description is given in the following subsections.

2.1 Full Matrix Capture

FMC is an acquisition process that obtains all the A-scans (amplitude time series) between all individual pairs of transmitter and receiver probe elements. These elementary A-scans are stored in the FMC data set. To achieve the best focusing result, all of the elements constituting the full aperture of a probe should be used to generate the FMC data set through synthetic beamforming. In this case, the number of acquisitions required to build the FMC data set is equal to the number of elements of the probe. The FMC data set contains all the sound propagation information between each element of the probe, including reflections at interfaces and scattering by flaws.

2.2 Phase coherence imaging

PCI is an amplitude-free technique. Its signal processing is based exclusively on the phase information of the elementary A-scans used to generate a TFM image. PCI is a powerful technique for identifying defects that are poorly oriented or very small, such as high-temperature hydrogen attack, but it avoids the problems associated with Time of flight diffraction TOFD. Because the TFM acquires the volumetric data, the defects can be located and sized in all directions. The final image using the PCI mode is also completely independent of amplitude. Relying on the signal’s phase rather than the amplitude means that even in materials with high attenuation or background noise, the coherence of the signal can still be evaluated since the frequency distribution can be found even with low signal amplitude. PCI can be very effective for weld inspections since it combines the advantages of reflected signals like phased array and the tip-diffraction phase information like TOFD. Another advantage of PCI is that fewer groups are required for the same scan coverage. [4]
3. Laboratory testing

For verification of using phased array testing and other advanced ultrasonic inspection techniques like TFM, PCI etc. samples cut from real steam pipelines of fossil power plants were used. Two different types of welds were delivered from fossil power plants for testing and verification of service-induced defects detection possibilities. One of piece was cut from mixing part of steam pipeline and second two pieces were cut from header end cap. All of the pieces were made from 15128 steel type.

3.1 Mixing piece from steam pipeline

All welds were operationally repaired from the outer surface. During the repair, the weld was ground to a depth less than half the wall thickness and filled with new weld. Ultrasonic testing was performed from the inner and outer surface of the welds, in the root region of the original welds, with the aim of detecting creep damage. During real on-site testing, measurements will only be possible from the outer surface. The main reason for performing testing from both surfaces was the possibility of scanning the largest possible volume of the weld joint. To detect the initiation of defects, i.e. defects of very small dimensions, it is important that changes in the structure of the material itself are visible in the ultrasound signal. This is mainly the edge of the welding joint or the interface between individual welds in the case of local repairs. An example of the detection of the interface between the original and the repair weld is shown in Figure 1.

![Figure 1. Example of interface detection between original and repaired weld](image)

3.2 Header end cap

End cap with relief radius is a common solution in headers located in economisers, evaporators, heaters and reheaters in 100 – 250 MW boilers built in seventies and as well as in later retrofits.
The header end cap welds can be tested with shear waves from the side of the pipe (a), as well as from the side of the end cap itself (b), or with longitudinal waves from the front of the bottom of the chamber (c). Ultrasonic testing using the phased array technique is performed along the entire circumference of the weld (a, b), or along its entire length (c), see Fig. 2.

For the actual execution of the tests, two cut-outs of the headers end cap with a thickness of 36 and 60 mm, Fig. 3. Available PA probes were tested on both pieces of cut-outs to determine which is most suitable for detecting possible creep damage.

After measuring the PAUT on a section with a thickness of 36 mm two pieces were cut to make the gauges. The side drilled holes in the gauges were designed to try to represent the smallest possible manufacturable artificial defects and adjusted from a geometry point of view. A drawing of the gauge with EDM holes with a diameter of 0.5 mm in the area of edge fusion and TOO is in Fig. 4.
Measurements of a cut-out with a bottom thickness of 36 and 60 mm were carried out with several probes with frequencies in the range of 5 to 10 MHz using several testing techniques. Testing directly from the surface of the bottom of the chamber turns out to be the most telling. Measurements were made for this probe arrangement and the results of the PAUT – TFM – PCI testing techniques were compared. Example of measurement by 5L64A32 phased array probe is shown on figure 5.

4. Conclusions

To test and verify advanced ultrasonic techniques suitable for detecting defects of the smallest dimensions (so that defects can be detected at an early stage of their formation), several test samples were obtained directly from the operating power plants. One of these samples was a repair weld sample where the interface between the repair and the original weld was clearly detectable. The resolution of ultrasonic technique must be such that the interface between the welded joint and the base material is clearly
visible. If there are places in the test area where the repair of the welded joint was carried out, this place must also be detectable in the ultrasound image.

Other samples came from a rather complicated and currently problematic type of weld joint located at the headers end cap from fossil power plants. The obtained results on these samples proved the suitability of the application of three positions of ultrasonic probes when testing the welded joint of the header end cap. The probe in the position from the bottom face can be applied in the entire range of bottom thicknesses. The suitability of the PA probe for testing from the outer surface of the pipeline must be verified for each configuration of thicknesses and geometry of the weld joint so that Raytracing is optimized, i.e. so that the opening of the angles covers as much of the weld volume as possible, including the root area. PA probes 5L64A32 from the pipe surface and 7.5L60A14 from the bottom surface are suitable for testing with the phased array technique. In order to obtain as much information as possible from the area of interest, it is advisable to further process the measured data and thus use the TFM and PCI techniques.

The calibration gauge with holes with a diameter of 0.5 mm is suitable for setting the test sensitivity for detecting possible creep damage.

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