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Advanced NDE inspection methods for detection of SCC in blade attachments and blade roots

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Abstract

Power plant operators are often forced to make "release-repair-replace" decisions concerning components failed or reaching their designed life, thus reducing their availability. Possible failure of components, functional loss and personnel injuries therefore can't be excluded. Therefore, an adequate assessment of the remnant life of steam turbine components is a key issue in life management of steam turbines, and, therefore, in optimisation of inspection and maintenance concepts of power plants.
To prevent such events, a defect assessment procedure needs the assessment of the actual and exact material condition of stressed components.
Investigation of service lifetime of turbine components gains therefore considerably significance. SIEMENS Power Generation Group (Siemens PG) has developed a concept for service life analysis of highly-stressed turbine components which takes account of factors such as year of manufacture, i.e. the forging process, materials and service conditions to enable power plant operators to initiate timely actions to ensure future safe and reliable plant operation. In addition to material databases which contain not only material criteria but also act as a repository for long-term empirical data, nondestructive examination (using ultrasonic, eddy-current, magnetic-particle and liquid penetrant techniques) has an increasingly important role to play in providing precise descriptions of the condition of examined turbine components. Especially test methods, which ensure mechanized in-situ tests without additional expenditures for disassembling of blades and blade attachments are required to fulfil the prerequisites of the service- NDE on power plants.
The paper describes several advanced inspection techniques, which ensure an reliable ultrasonic inspection of LP turbine blade attachments during outages. The used inspection technique allows the inspection of blade attachments grooves of an nuclear LP turbine rotor were even smallest indications of possible defects can be detected.
Furthermore the application of advanced phased array inspection technique for blade roots of LP turbine rotor is described. By using this advanced technology an inspection of the most critical areas of blade roots is possible without dismantling from the rotor.

Keywords: Turbine inspection, Phased Array Inspection, Blade Root Inspection, Blade Attachment Inspection

1. Introduction

International competition in the field of power generation is increasing and customers are demanding economic and efficient power plants. In the long term, continuous power plant availability can only be guaranteed through an effective mode of operation in conjunction with a systematic maintenance and inspection concept.
Apart from boiler, steam piping and valves, the rotating components of the turbine/generator (turbine and generator rotor) also belong to the most highly stressed components in a power plant. Loads result for example from operating parameters, the mode of operation of the ma-

chinery, startup processes, thermal stresses, prestressing, residual stresses from the manufacturing process, as well as loading from the centrifugal forces acting on the rotating components. During scheduled outages, highly-stressed components are subjected to non-destructive testing designed to reliably detect any possible service-induced damage (e.g. cracking) before this can lead to failure of a component and severe consequential damage. For example, damage to a blade in the low-pressure turbine of a South African power plant (600 MW) in January 2003 resulted in the entire turbine generator unit being destroyed. Quite apart from the risk to personal health, such damage can lead to unscheduled outages and plant downtime, as well as unplanned costs for expensive repair and maintenance work on the turbine/generator. In comparison to these risks, the cost of inspecting such highly-stressed components is easily justified, as is the need for reliable and qualified techniques in the field of non-destructive testing.

The following describes two examples for non-destructive techniques used on turbine blade roots and blade attachment grooves.

3. Ultrasonic technique for inspecting turbine blade roots in-situ

The blades in a steam turbine belong to the most-highly stressed components in a turbine/generator. The high turbine speed (3000 rpm) and the dead weight of the blades means that the last-stage blades in a steam turbine are subjected to enormous centrifugal forces during plant operation. The roots on such blades are designed and calculated using the most up-to-date methods to allow them to accommodate these high loads. Particularly during transient loading conditions (startup and shutdown processes) certain areas of the blade roots and blade attachment grooves are subjected to high stressing. Under unfavorable conditions, unusual events occurring during operation of a turbine (e.g. loss of vacuum, overspeed) can result in damage to blading, with possible crack initiation in the highly-stressed areas of the blade root and subsequent service-induced crack propagation. In addition steam purity is also an important criterion regarding the susceptibility of a turbine blade to corrosion. If the steam is polluted with chlorides this is one of the basic prerequisites for the occurrence of corrosion fatigue in turbine blades, blade roots and blade attachment areas.

In the light of such influences on safe turbine blade operation, the necessity for non-destructive testing becomes particularly apparent. Turbine blades and their roots should be examined non-destructively at predetermined intervals to allow timely detection of any damage and the replacement of affected blades.

The task faced here was to develop an ultrasonic testing technique for a special type of blade root to allow inspection of the roots of the last-stage blades in the rotor of a low-pressure steam turbine. When installed in the rotor the most highly-stressed areas of the blade root are not accessible for standard crack testing techniques. The objective was therefore to develop a technique which allowed these highly-stressed areas of the blade root to be inspected in situ, i.e. without removing the blade. The examination system had to provide reliable and reproducible results while remaining cost effective.

3.1 Theoretical investigations

Extensive theoretical investigations had to be performed before any decisions could be made regarding selection of the ultrasonic examination technique. The blade under investigation was a last-stage blade from an LP turbine rotor (Type: NL 5m^2).

Figure 1 und 2 show the root for such a blade. Performance of the inspection on the blade roots of the dual-flow turbine rotor required that a calibration block be fabricated for the right and left side.

Figure 1
Blade root of an LP turbine rotor with artificial flaws, pressure side

Figure 2
Blade root of an LP turbine rotor with artificial flaws, steam outlet area

Reference reflectors (grooves, 3 mm long, 1 mm deep) were introduced into these calibration blocks at the most-highly-stressed areas. These areas can be found on the pressure side in the vicinity of the leading/trailing edge of the blade root in the first serration of the fir-tree root as well as in the middle of the first serration on the suction side of the blade root.

As the turbine blades to be examined have an extremely complex 3D geometry, 3D drawings were used to determine the theoretically-optimum beam angles and scanning positions. This involved projecting sectional planes into the blade root drawing to simulate the sound beam path of ultrasonic probes for various possible scanning positions and also involved the use of 3D ultrasound simulation programs.
The theoretical investigations showed that it is indeed practicable to select scanning positions at the blade root which allow reliable detection of the reference reflectors. Along the complex geometry of this blade root these scanning positions were also situated in radii and on other curved surfaces which required a customized inspection solution for the component in question. For this reason, it was decided to fabricate specially-fitted pieces for each area to be scanned, which would allow exact positioning of the ultrasonic Phased Array probes. This inspection technique seemed to be the right solution for the inspection problem, providing a suitable tool for power plant inspection services.

3.2 Development of a Component-Specific Examination System

Based on the theoretical investigations, five scanning positions per blade root were determined which ensure reliable examination of the defined highly stressed areas. Reliable detection of all existing reference reflectors was demonstrated by practical examinations on the provided calibration blocks using these scanning positions. The practical examinations were performed using phased array probes at various frequencies. A 16-element phased array probe and a horizontally vibrating probe with 16 elements proved to be very well suited for the described examination task.

For all reflector positions, comparison measurements were performed both on the calibration blocks with artificial defects as well as on identical defect-free calibration blocks. The investigations were performed using the OMNISCAN (ZETEC) phased array examination system. Figs. 3 and 4 show an example of the documented sector scans for a selected scanning position.

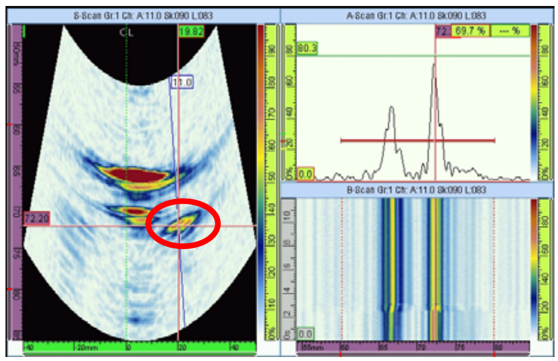

Figure 3
Scanning position : center, right hand blade flaw # 3

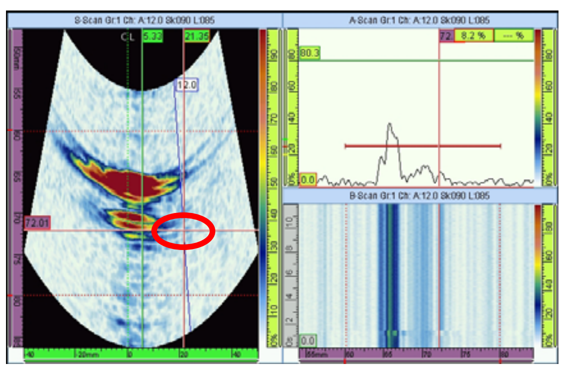

Figure 4
Scanning position 1, right hand blade, without artificial defect

After qualification of the examination method for all defined examination areas, adapters were prepared to ensure reproducible positioning of the probes in on-site examination. Fabrication of these contoured probe holders had to account for the fact that the final stage blades are subject to a specific manufacturing tolerance. Investigations on several blades of this type confirmed that the geometric deviations between the blade roots due to the manufacturing tolerance are negligible. The (slight) deviations which still occur can be compensated for by the couplant used (gel). Coupling is monitored using the geometrical reflectors, the appearance of which was documented during development of the examination method.

The first examination using this examination method was performed successfully in January of 2004 in a power plant in South Africa. The examination proved to be reliable and very well suited to providing conclusive statements regarding the critical areas of final stage blades in the shortest possible time. Meanwhile a lot of turbine shafts have since been examined using this method.
Based on the experience of app. 30 Phased Array blade root inspection in the field further improvement of the inspection technique was reached by implementation of a mechanized inspection technique. A small manipulator ensure an encoder driven movement of the Phased Array probe. The UT data will be recorded online. So the complete serration of the blade root is covered by Phased Array UT inspection. Fig. 5 shows an example of Phased Array UT results of an mechanized Phased Array Blade Root inspection of an LP blade root. In this case 6 artificial notches in different positions (flaw# 5, 6, 7, 8, 9 and 10) were detected reliable. The implementation of mechanized Blade Root inspection in turbine field service will increase the covered areas in the blade root and improve reliability detectability.

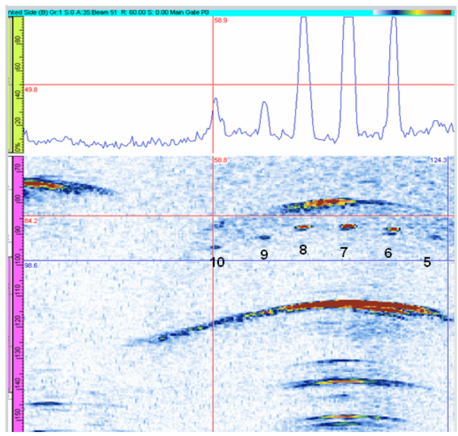

Figure 5
B-Scan of a mechanised Phased Array Inspection of an LP blade root (Siemens design)

4. Ultrasonic Examination of Radial-Entry Pinned Blade Roots on 900 MW LP Turbine Shafts (ALSTOM design)

4.1 Task Definition

Radial-entry pinned blade roots on nuclear LP turbine shafts (900 MW) must be periodically subjected to ultrasonic examination for incipient cracks in the area of the upper pin hole. Examinability of turbine blade roots is influenced primarily by the following factors:

- Accessibility
- Presence of a preferred orientation of the defects to be detected
- Geometry of blade root.

It is known that incipient cracking can occur in the area of the pin holes under certain conditions in pinned blade roots. In contrast to blade roots with firtree design (where the probable orientation of anticipated cracks is known), the examination of pinned blade roots is complicated, as in this case cracks can develop with various orientations, which has a significant effect on detectability by ultrasound. Previously, the examination of such blade roots was performed primarily by means of conventional UT examination, which resulted in a relatively large number of errors in detection and size estimation due to the conditions described. The development of a phased-array ultrasonic examination method is described below which enables detection and size estimation of cracks in pinned blade roots. The examination method must be capable of reliably detecting incipient cracks, and determining their size.

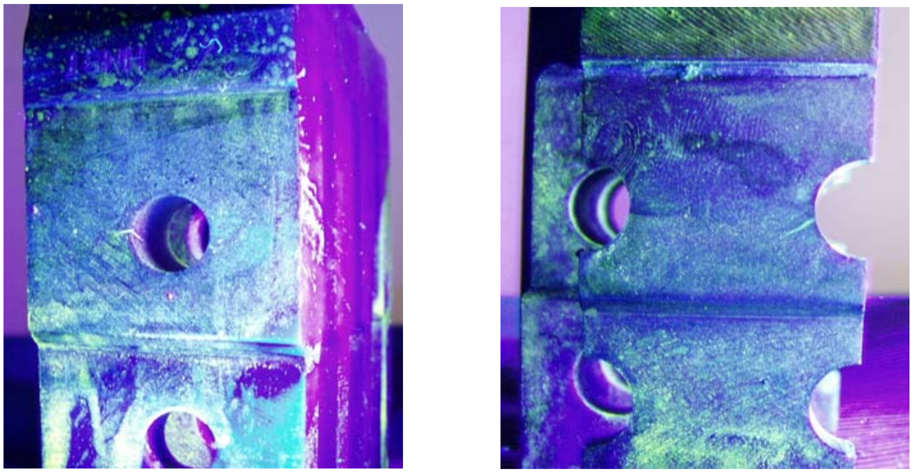

Figure 6 + Figure 7
Pinned blade roots, cracked in upper pin hole

4.2 Development of a Phased-Array Ultrasonic Examination Method

After studying the examination problem, it was decided to solve it using phased-array ultrasonic examination. In order to accommodate the task definition, it was necessary to prepare a large number of calibration blocks. The calibration blocks represent the geometry of the outer fingers of the blade roots in rows 4 and 5 of the LP turbine shaft. Artificial defects of various sizes and with various orientations were introduced in the area of the upper pin hole.

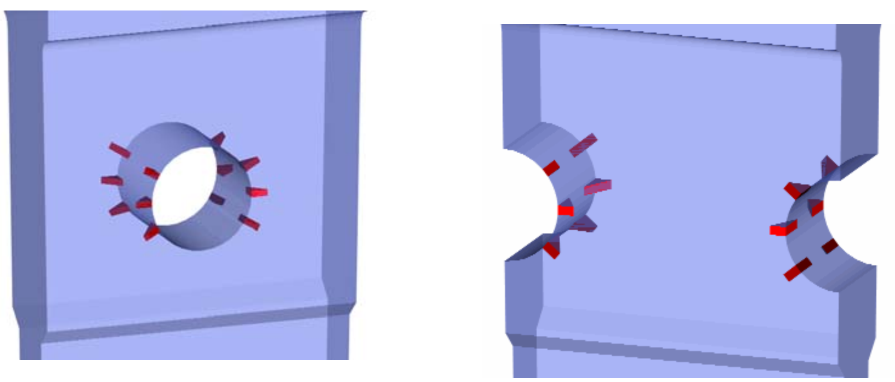

Figure 8 + Figure 9
Calibration blocks for blade rows 4 and 5 with artificial defects

To ensure the most effective possible examination method, a 64-element phased-array probe was selected . The 64-element probe is essentially subdivided in three 24-element phased arrays. All sequences are in turn composed of 120 shots which are sequentially steered towards 120 focal points. The focal points are spaced equidistantly along a line which was defined in the area of the anticipated defect range. The selected examination method can thus be used to scan the entire anticipated defect area of the upper pin hole by simply positioning the probe.
4.3 Qualification of Examination Method on Calibration blocks

Several calibration blocks were prepared for each blade row. Each calibration block represents an exact copy of an outer finger of the blade root. 15 calibration blocks with artificial reference reflectors of differing size and orientation were available for validation. An additional 20 blades with natural cracks were available for comparison of the reflection behavior of artificial defects with that of natural cracks. The tests were performed using the Multi- X (M2M) phased-array system. Two wedges were used to enable the detection of incipient cracks both in the area of the outer end face of the outer finger as well as in the area of the inside of the outer finger of the blade root. These wedges yield the respective beam angles which are specifically required for scanning of the inside or outside of the finger of the blade root. All of the shots in a sequence are displayed as a B-scan. A total of 3 B-scans are visible (Fig. 10). This examination method enables evaluation of the entire anticipated defect area with a single placement of the probe. Fig. 10 shows the examination of a calibration block for blade row 4 as an example, with 2 artificial defects at different angles on the inside. (notch, edge length: 2 mm, orientation: +30° (green) as well as 2 mm at an orientation of -45° (red).

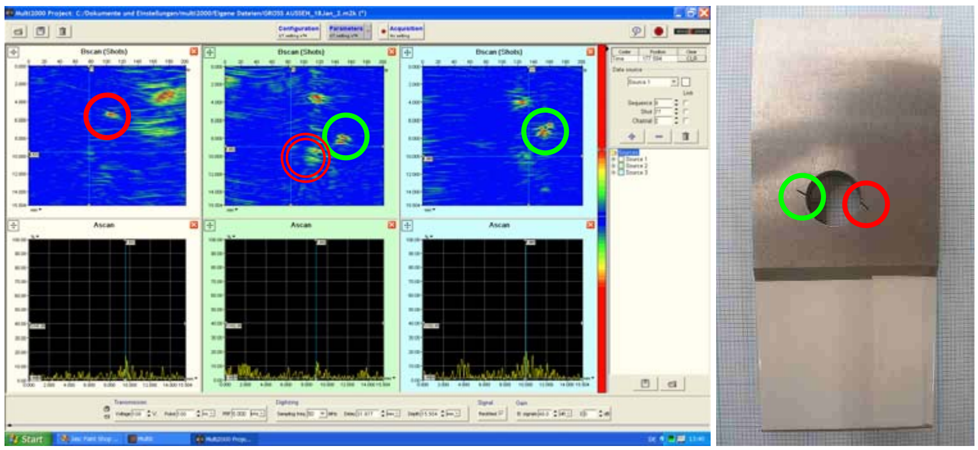

Figure 10
Examination result for the example of a calibration block with two artificial defects on the inside

4.4 Qualification Results and Conclusions

It was demonstrated based on the measurements on the calibration blocks that the described phased-array ultrasonic examination method is suitable as a service test method for in-situ examination of the highly-stressed areas of pinned blade roots in rows 4 and 5 of 900 MW LP turbine shafts for incipient cracks.
The developed examination method reliably detects incipient cracks in the area of the upper pin hole with an edge length of > 0.5 mm. The extensive investigations performed on calibration blocks as well as on blade roots with natural cracks were subjected to a detailed evaluation. The examination method was used for the first time successful in August 2005 in a European nuclear power plant.

5. Summary

Use of the phased-array ultrasonic examination method enables fast and reliable ultrasonic examination of test objects with complex geometries. Especially for turbines, this examination method is therefore increasingly being used in the examination of blade roots and blade attachment grooves. This especially saves the time required for disassembly and reassembly of components in conventional crack examinations. Examination methods which provide for exact crack size determination enable computer evaluation of the detected indications and, if necessary, limited release of components with defect indications in order to plan and prepare for a requisite replacement of components during for the next turbine inspection outage.

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