

Advanced Ultrasonic application for the inspection of turbine components

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Abstract

Today world wide a big number of Power Plants already reached or exceeded their designed life and therefore reduce their safety and availability. During operation, several turbine components suffer performance changes and a reduction of their loading reserves. Crack initiation and crack growth can lead under service conditions to damages on components and has been probably already influenced by operating- or environmental conditions.

Adequate assessment of steam turbine components is a key issue in life management of steam turbines.

To prevent any further 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 Energy Service 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 Ultrasonic 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 shafts, turbine blade attachments and blade roots during outages. The used inspection technique allows the inspection of blade attachments grooves of turbine rotors, were even smallest indications of possible defects can be detected.

1. Introduction

Nondestructive examination is an important means of determining the condition of highly-stressed turbine and generator components during inspections of the turbine generator. Both conventional examination methods (dye penetrant examination, magnetic particle examination, ultrasonic and radiographic examination) as well as part-specific special examination methods are used for nondestructive examination of areas which are especially highly stressed (and thus also especially at risk).

Over the course of inspection planning, examination scopes are defined based on the turbine design, the materials used and the turbine generator operating mode; these are then implemented during the turbine inspection.

Given that operating steam turbine generators are operated beyond the projected service life of 200,000 operating hours, the availability of nondestructive examination methods for selected areas of the turbine takes on great significance. The objective is to reliably determine the condition of the turbine with a high degree of detection sensitivity before it is returned to operation for 8 to 10 more years. Siemens Energy Sector has elaborated a concept for service life analysis of steam turbine generators which forms the basis for life-time extension measures on the turbine generator. The capabilities of special examination methods for turbine service will be described below using examples of examinations performed (and detected inspection findings).

2. Examination of Steam Turbine Shafts

The actual turbine shaft is one of the most highly-stressed components in the steam turbine generator. It is subject not only to the high dynamic loading resulting from an operating speed of 3000 rpm, but it is also subject to thermodynamic and corrosive loads. The cumulative effect of factors means that damage can occur in many different areas of the turbine shaft as a result of service loading. Knowledge of the loads on the components as well as of the material behavior, manufacturing process and release test is a prerequisite for the definition of nondestructive examinations.

Several examination methods which are used in outage inspections on turbine shafts will be explained below.

2.1 Ultrasonic and eddy current examination of bores in turbine shafts

In the past, bores (axial bores or radial bores) were introduced in turbine shafts during fabrication of the forging in order to remove material specimens to obtain reliable information on the material properties of the forging. These bores were sometimes also used specifically for the removal of indications.

It is known that stresses are increased in the vicinity of the bores, and therefore the critical flaw size is much smaller than in the remaining volume of the rotor.

It is therefore very important to inspect the zones adjacent to the bore surface using suitable testing techniques. The mechanized test techniques available today permit rational and reliable compilation of information and assessment of findings.

Measurement of the bore diameter in turbine shafts subjected to high heat loads (high-pressure and intermediate-pressure turbine shafts) is also highly important. It is known that turbine shafts in the area of the steam inlet are subject to high thermal loads. Slight widening of the diameter of the axial bore in the inlet area of the turbine shaft is a reliable indication of creep damage in such shafts.

The diameter of the axial bore in HP and IP turbine shafts is therefore measured over the entire axial length during major turbine overhauls.

SIEMENS Power Generation Group examines bores in turbine and generator shafts using the BORIS portable bore inspection system. This system consists of a manipulator with drive unit, a digital ultrasonic device and an eddy-current unit. It ensures high-sensitivity eddy-current examination of the cylindrical bore surface as well as ultrasonic examination of the zone around the bore surface. The combination of mechanized eddy-current examination (as a surface crack detection technique) and ultrasonic inspection of the zone adjacent to the bore enables high-sensitivity examination for forging

flaws in bore areas, thus allowing reliable data to be provided on the operational safety and reliability of turbine shafts.

Eddy-current examination is carried out using high-sensitivity rotary probes equipped with both absolute and differential probes. Examination is carried out using the absolute probe, with verification using the differential probe in the event of an indication.

Ultrasonic examination is carried out using the TOMOSCAN multi-channel digital ultrasonic device. Four focused two-crystal probes enable scanning in four different directions. This ensures reliable detection of flaws in an area up to 30 mm from the bore surface.

2.1.1 Bore Inspection of a 500 MW HP- Turbine rotor in Germany (NON Siemens)

An examination carried out on a high-pressure (HP) turbine shaft will be used to demonstrate the capabilities of the BORIS bore inspection system.

A single indication (equivalent to a circular reflector size 5.5 mm in diameter) was identified in the gland area during ultrasonic volumetric examination from the outside surface of an HP turbine shaft of Russian design (LMZ). This indication was located approximately 26 mm from the surface of the through axial bore. No indications were identified during surface crack testing of the axial bore. Ultrasonic examination from the axial bore confirmed the indication detected from the outside. An angular oriented indication (26-31 mm from the bore surface) approximately 62 mm long was identified. Analysis of the recorded echo dynamics enabled a radial extension of 7 mm to be determined. Figure 19 shows the results of the ultrasonic volumetric examination (from the outside surface) and the ultrasonic examination from the bore.

Fracture-mechanics analysis of this flaw led to the assessment that the flaw was unallowable in terms of safe and reliable continued operation of the turbine shaft.

It was decided to machine away the flaw area in stages while carrying out a surface crack examination (MP examination) to determine the actual flaw size.

The indication was exposed at a depth of 31 mm from the original bore diameter. Figure 21 shows that the indication exhibited an axial extension of approximately 38 mm at this depth.

However, this does not represent the complete axial extension of the flaw, as the tube-type forging flaw exhibited an oblique orientation in the axial direction, and this meant that the full extension could not be exposed.

Assessment of all examinations carried out (step-by-step machining-away of the indication area was carried out in 2.5 mm stages, with an MP examination carried out after each stage) showed that the total axial extension of the tube-type forging flaw was 58 mm, and the distance from the original bore diameter was 26 - 36 mm.

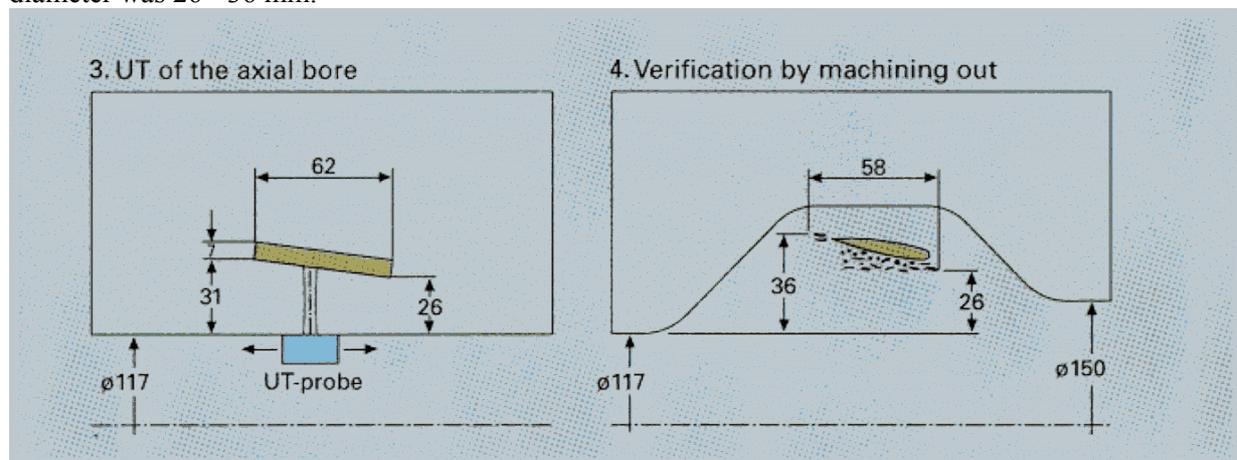


Fig 1
UT results of rotor bore inspection of axial bore of the HP rotor

Fig. 2
Shape of the axial bore after machining the findings (true length of flaw: 58 mm)

tangential

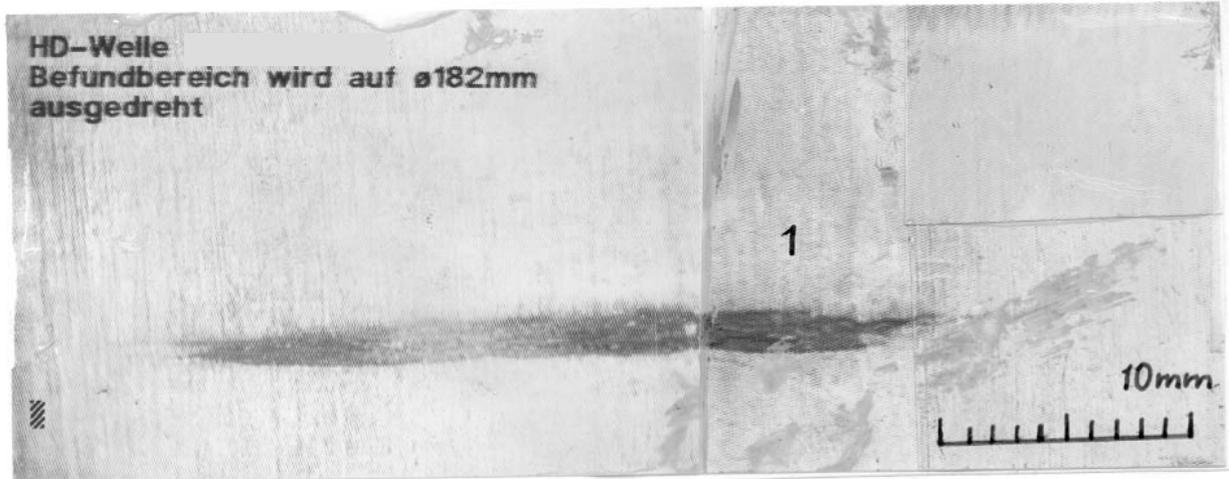


Fig 3

Result of MT inspection of the axial bore during machining of bore diameter

Thanks to the measuring accuracy, relatively good agreement was obtained between the flaw size determined using ultrasonic bore inspection and the actual flaw size.

The described example of ultrasonic examination of an HP turbine shaft shows that the combination of ultrasonic volumetric examination (from the outside surface) and inspection of bores from the bore surface using the BORIS inspection system provides satisfactory data on the condition of turbine and generator shafts. The above-mentioned techniques enable detection, sizing and orientation description of all stress-relevant flaws.

Out of a total of approximately 500 examined turbine shafts, indications were removed by machining away or increasing the bore diameter in 35 cases, enabling the turbine shafts concerned to be returned to service after the corrective actions.

2.1.2. Ultrasonic bore examination of an IP turbine shaft in Greece (NON Siemens)

It was necessary to requalify an IP turbine shaft in a turbine modification in Greece, as this turbine shaft was modified and reused. Ultrasonic and eddy current examination of the center bore through the shaft was performed.

Measurement of the bore diameter over the entire length of the axial bore must be performed before honing of the bore surface in preparation for ultrasonic and eddy current bore examination (fine grinding of the surface to establish a high surface quality) in order to identify any creep damage in the area subjected to high heat loads. Fig. 4 shows the results of an inspection of an center bore in a 300 MW intermediate-pressure turbine shaft for creep damage. In this case, significant widening of the diameter of the axial bore was detected in the inlet area.

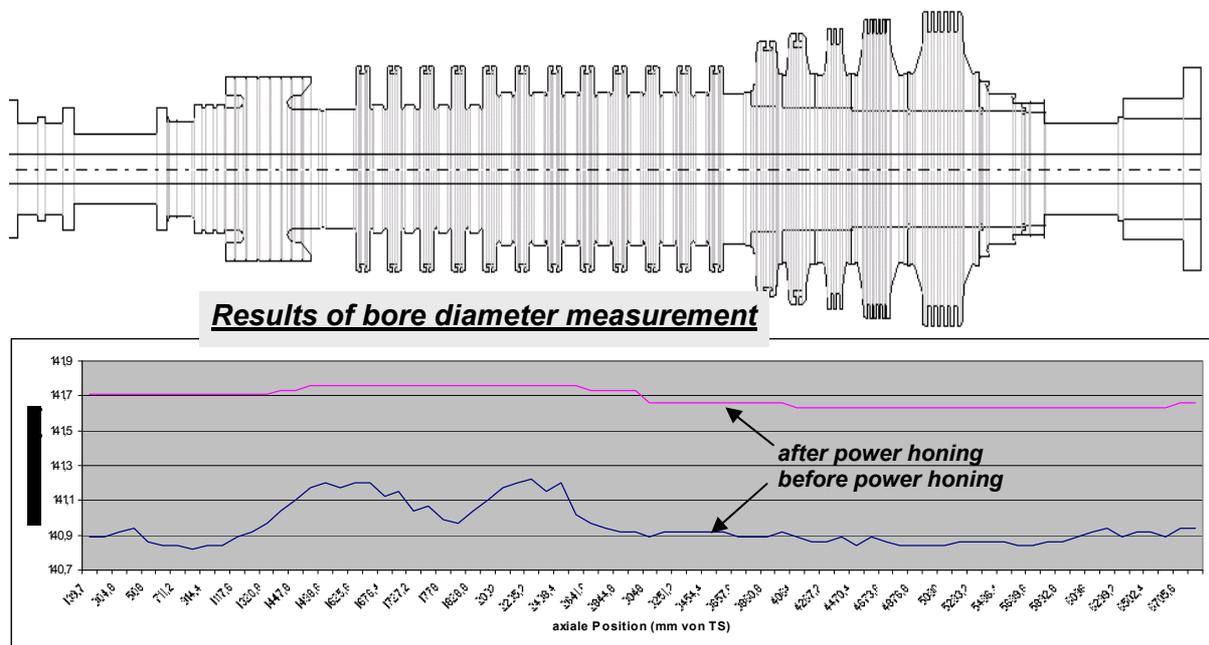


Fig. 4: Measurement of bore diameter for detection of creep damage

In both the UT and ET examination, an unusual indication (orientation in the circumferential direction) was detected in the area of the labyrinth piston with both the ET and UT examinations. The detected indication was an incipient crack in the circumferential direction which had already developed to an extent of 50% around the circumference of the bore surface. Ultrasonic examination revealed a crack depth of approx. 5 mm. The bore diameter was deliberately enlarged using the information from the nondestructive examinations so that the detected crack could be completely removed. The turbine shaft could be modified as planned in the turbine modification and returned to operation.

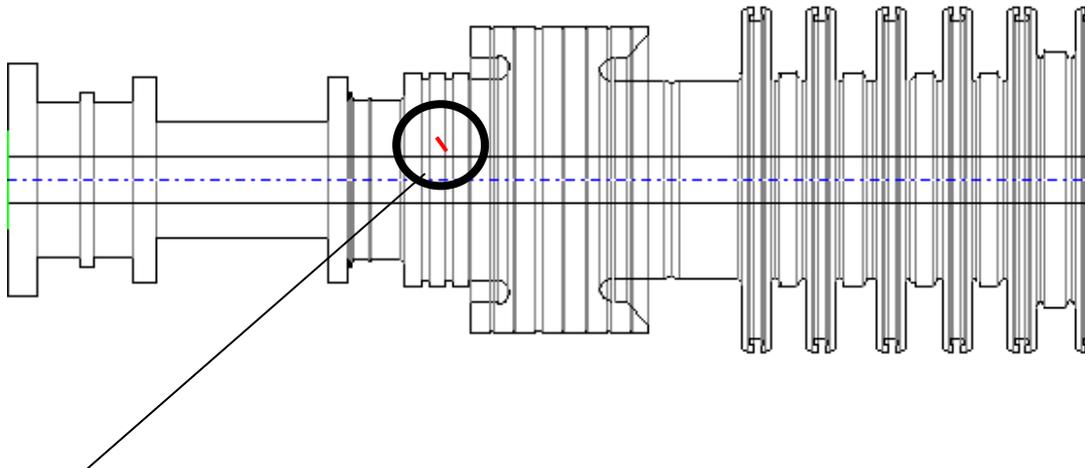


Fig. 5: crack detected on bore surface of an IP turbine shaft (NON Siemens design)

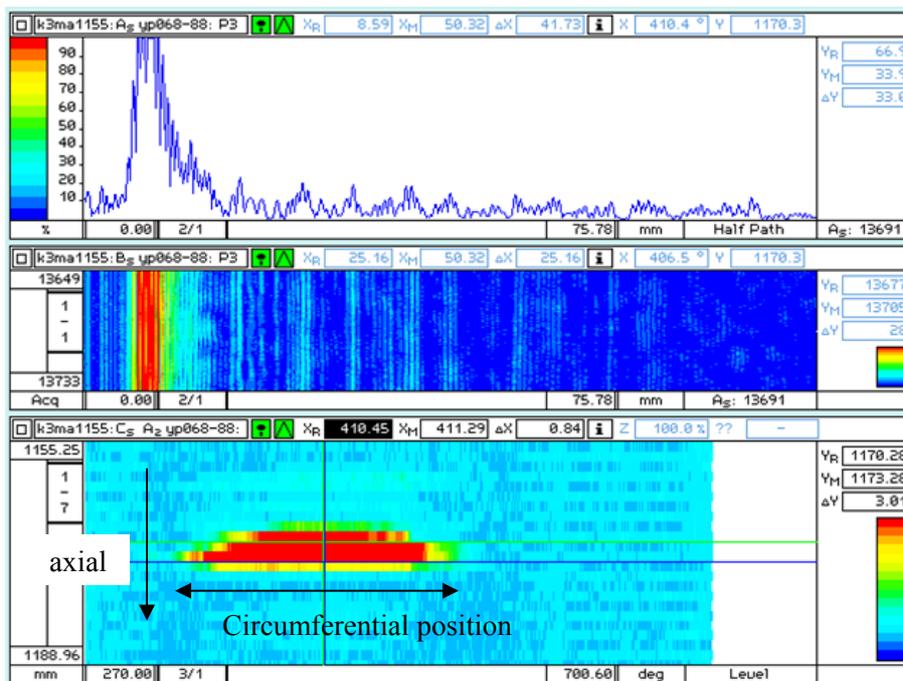


Fig. 6: UT results of bore examination (scanning direction from bore surface: axial/radial)

2.2 Ultrasonic Phased-Array Examination of Blade Attachment Grooves

During operation of a steam turbine, the turbine moving blades as well as the blade attachment grooves are subjected to especially high loads. Depending on the engineering and design of the turbine shaft, selected blade stages may be subjected to very high loads. If the loads resulting from turbine operation are aggravated by corrosion-promoting factors resulting from the water chemistry, blade attachment grooves in particular can suffer damage due to stress corrosion cracking. The role of nondestructive examination methods will be explained for the example of several investigations for blade attachment grooves on an HP/IP turbine shaft (110 MW) in Poland.

Heavy damage occurred in an HP/IP turbine shaft in a steam turbine in Poland (manufacturer: ZAMECH ELBLOG) in 2004. The turbine stationary blading was heavily damaged as a result

of stress corrosion cracking in the blade attachment groove for moving blade row 7 on the turbine shaft. It was then necessary to subject all turbine shafts of the same design to nondestructive examination in order to identify any similar damage to the blade attachment grooves of the HP/IP turbine shafts in a timely fashion.

Siemens Energy Sector/Field Service was commissioned in March 2005 to develop an ultrasonic method with which the highly-stressed areas of the blade attachment grooves can be examined.

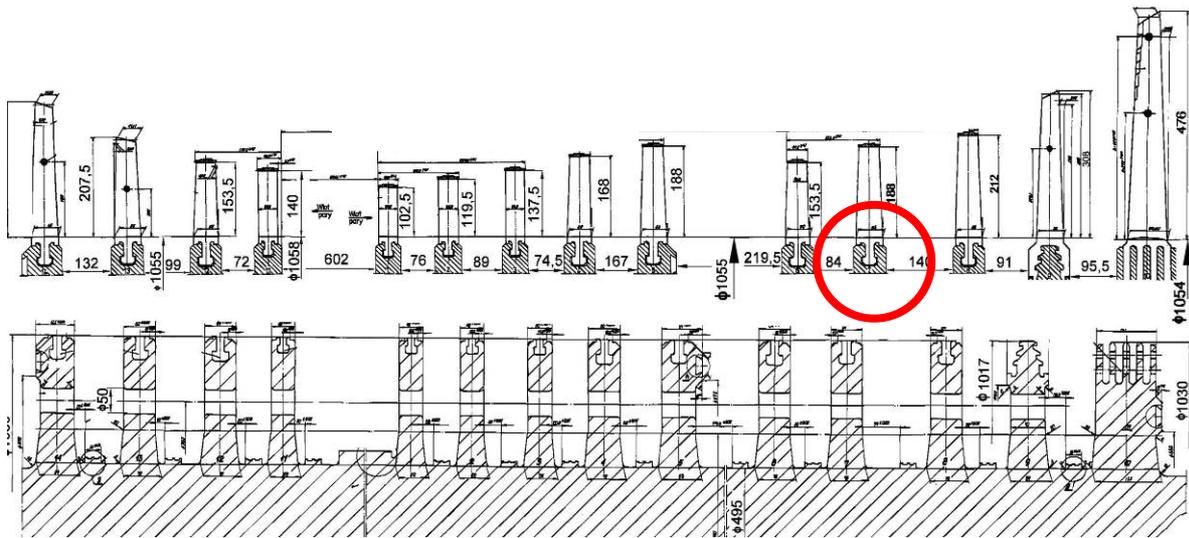


Fig. 7: 110 MW HP/IP turbine shaft/blade grooves to be examined

The primary purpose of the project was the development of a phased-array ultrasonic examination method for blade grooves with the so-called "T-groove" design, as 12 of the 14 blade attachment grooves had this design. The grooves for blade rows 13 and 14 (so-called "fir-tree design" in row 13 and "radial entry pinned blade root design" in row 14) were examined by conventional examination methods. The groove for the blade row which resulted in damage due to stress corrosion cracking in 2004 is indicated in Fig. 7.

Prerequisite for reliable ultrasonic examination during turbine service projects is validation of the procedure before application in practice. In such cases, such a validation is performed on test blocks which embody the identical geometry of the component to be examined. In the areas of the blade grooves to be examined in which defects (cracks) are anticipated, artificial defects were introduced in order to investigate their detectability by ultrasonic examination.

Development and validation of the phased-array ultrasonic examination method for examining T-grooves in the 110 MW HP/IP turbine shaft in Poland was completed in only 2 months, with the result that the first examination of a turbine shaft was performed in May 2005. The blade grooves were examined with an automated examination system consisting of a simple two-axis manipulator, an encoder system and the phased-array ultrasonic instrument. The turbine shaft was set down on power rollers and turned at a constant speed of 1 to 1.5 rpm for the examination.

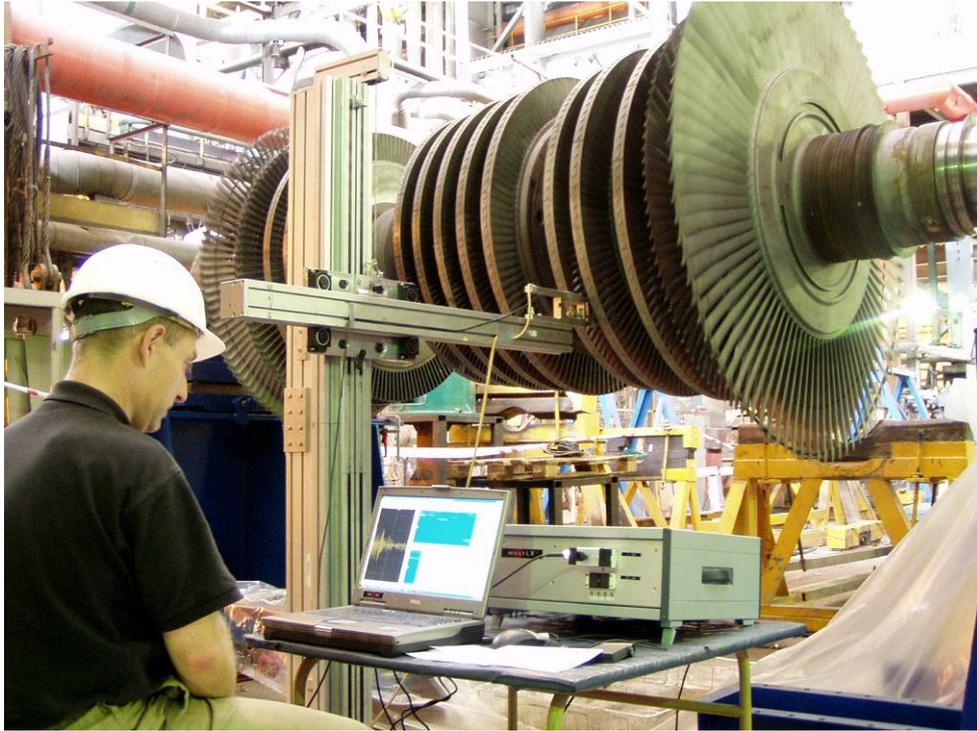


Fig. 8: Automated phased-array ultrasonic examination on blade attachment grooves in an HP/IP turbine shaft in Poland

The manipulator enabled reproducible examination of all of the areas at risk in the blade grooves.

The examination revealed indications in the area of anticipated defects in the blade groove of blade row No. 7. As the damage in an identical turbine shaft in 2004 could also be attributed to stress corrosion cracking in the blade groove of row 7, it was decided to remove the blades in the affected blade row and to perform conventional crack examination. This crack examination confirmed the indications detected by phased-array ultrasonic examination.

Ultrasonic examinations were performed by Siemens Energy Sector on a total of 3 HP/IP turbine shafts in Poland in 2005. These examinations revealed indications in the blade grooves in row 7 in all 3 of the examined HP/IP turbine shafts. In all cases, the indications were confirmed by conventional crack examination (MT examination) after blade removal. The presented procedure with phased-array examination on blade attachment grooves enabled the timely detection of and initiation of refurbishment measures on cracks in critical areas of the grooves.

2.3 Ultrasonic phased-array examination of radial entry pinned blade roots

The blades and blade attachments in a steam turbine belong to the most-highly stressed components in a turbine/generator. The high turbine speed (3000 rpm) and the dead 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 unfavourable 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 addition to the operational stress situation, steam purity and the corrosion susceptibility of the used material play an important role regarding the occurrence of corrosion fatigue or stress corrosion cracking in turbine blades, blade roots and blade attachment areas. Due to these facts, advanced non-destructive examination methods are required to ensure the safety and availability of the unit.

Radial Entry Pinned blade roots are a common design of several turbine manufacturer. Fig. 9 shows an example of this type of blade roots. The blade roots will be stacked in the invers contour of the rotor and locked by pins.

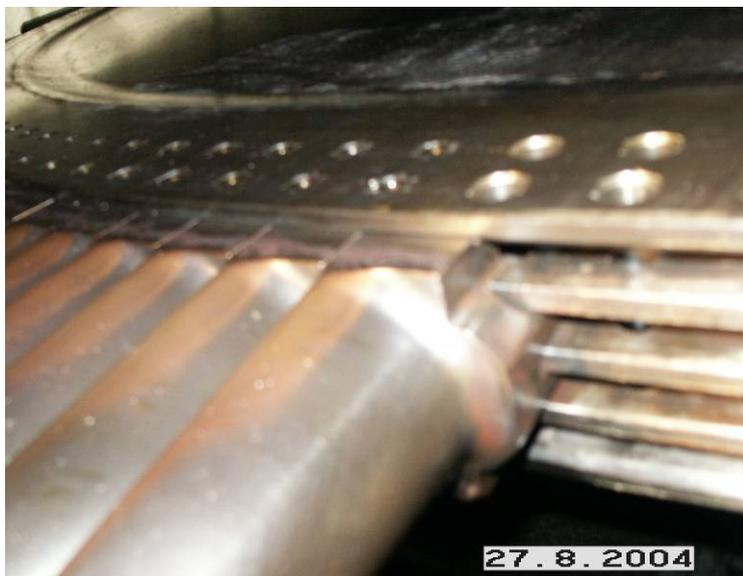


Fig. 9: LP Turbine rotor with radial entry pinned blade roots

During operation of the turbine the area around the pin holes is loaded by very high stresses. Depending of the used pin design the pin holes of the blade roots prefer to crack at the upper pin hole. If such cracking will not be detected during scheduled inspection, a blade failure with heavy damages at the complete turbine can not be excluded. Because this it is important

to have a reliable and sensitive inspection method available for the inspection of finger forked blade roots.

2.3.1 Development of the inspection technique

To develop an advanced UT inspection technique for finger forked blade roots, all conditions has to be taken into consideration. So, the following facts has to be taken into account:

- Accessibility for UT inspection
- Orientation of the cracks
- Location of the cracks

After theoretical investigation it was decided, that a Phased Array Ultrasonic Inspection should be used for this application. The good accessibility allow the use of linear Phased Array probes. The main reason for this decision was the fact, that the cracks to be detected occurring in different orientations. So a number of various beam angles will be required to detect all relevant cracks.



Fig. 10 : Typically cracked radial entry pinned blade root

2.3.2 Qualification of the inspection technique

To ensure the detection of flaws with different orientation several test blocks were manufactured. These test blocks include artificial flaws with angles of $\pm 30^\circ$, some up to 45° , from the ideal horizontal orientation.

To cover a wide range of the area near to the pin holes, a linear Phased Array Probe was developed and built. This Phased Array probe is able to cover the complete area, where the cracks will be expected.

The Inspection of the blade roots will be performed by using 3 inspection sequences on time. The elements of the used linear Phased Array probes are divided in 3 sequences. All the three sequences working in parallel and cover a special defined area.

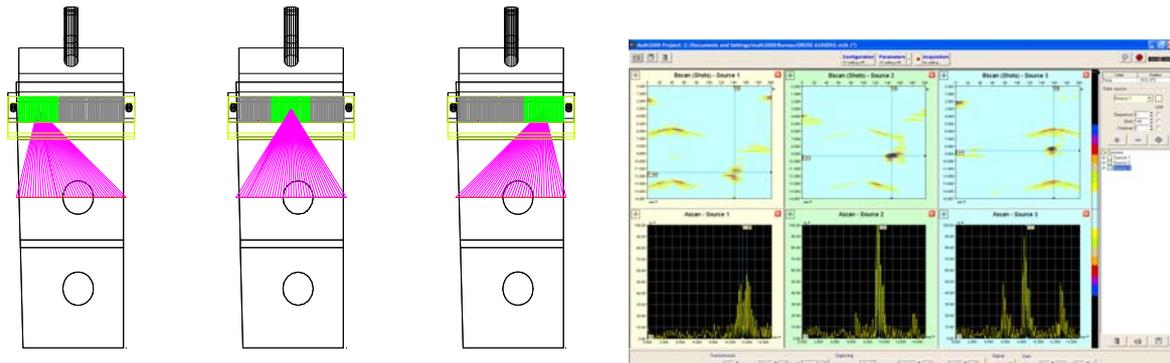


Fig. 11 : Linear Phased Array Probe operating in 3 sequences in parallel

The investigation at the test blocks and especially at real cracked blades confirm accurate, that this inspection technique is suitable to detect smallest cracks in the area of the upper pin holes of radial entry pinned blade roots. A procedure for crack- sizing was developed to allow an evaluation of the results of the Phased Array Inspection and if necessary the control of cracked blade roots for a limited time period.

Ultrasonic field has been computed for each blade and for the three positions A, B and C. We defined max probe angle i.e. the angle above which the acoustical field become inappropriate for the inspection.

4. Conclusion

Various nondestructive examination methods for the investigation of selected highly-stressed areas in a steam turbine shaft were explained in the examples presented. The phased-array ultrasonic examination method provides the possibility of efficiently and reliably examining blade roots, blade attachment grooves and shrink-fitted turbine wheel disks in conjunction with modern manipulation methods. This minimizes any necessary disassembly work.

Because of the wide variety of designs for blade grooves and blade roots, each individual blade/groove design requires an individual examination method. The basis for reliable nondestructive examination on a turbine shaft is validation of the examination method before performance of the examination. Reliable examination is possible only in this way.

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