Advanced NDT Methods for Efficient Service Performance

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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. The most highly stressed components in a power plant include apart from the boiler, steam piping and valves, also the rotating components of the turbine/generator (turbine and generator rotor). Loads, for example, result from operating parameters, the mode of operation of the machinery, startup processes, thermal stresses, pre-stressing, 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. Quite apart from the risk to personal health, damage to turbine or generator components 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.

Siemens Energy has developed an inspection concept for steam and gas turbine generator units which provides for scheduled inspections depending on the configuration, mode of operation and the number of hours of operation of the turbine generator unit. This makes use of special, validated non-destructive testing techniques. These testing techniques have been developed to allow particularly highly-stressed components in the turbine generator unit to be tested reliably while keeping disassembly to a necessary minimum.

2 Aspects of Non-Destructive Examination of Turbine and Generator Components

Non-destructive testing is a very important aid to assuring the safety and availability of steam and gas turbines. That is why non-destructive examinations are a standard feature in schedules for turbine and generator maintenance inspections and overhauls.
To be able to perform non-destructive testing in the context of servicing turbines and generators, numerous technical, organizational and personnel qualification requirements need to be fulfilled to ensure high-quality testing performance and proper analysis and documentation of test results. EN ISO 17025/2005 is internationally recognized as the state-of-the-art standard for defining quality criteria in the context of non-destructive testing. While there are a number of commonly used non-destructive examination techniques such as visual inspection (VT), magnetic particle testing (MT), liquid penetrant testing (PT), ultrasonic testing (UT), radiographic testing (RT) and eddy current testing (ET), modern, component-specific techniques, such as phased-array applications, and mechanized UT or ET testing may also be used. Testing is performed in accordance with test procedures which must be approved and released by a suitably qualified test supervisor. The persons actually performing the tests must meet certain minimum requirements in order to cope with the specific demands made by the individual techniques.

As a global turbine manufacturer Siemens Energy Service Division offers turbine generator services on a worldwide scale. This involves a team of qualified testing specialists also working on worldwide basis. The Siemens Service organizational units in Germany, the UK and the USA work in close cooperation providing a regular exchange of inspection information and expertise between both sides of the Atlantic. This is particularly important in respect of evaluating fleet experience and drawing conclusions regarding the testing techniques to be used.

2.1 Inspection of Steam Turbine Blades

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 weight of the blades mean that the blades of the final stage 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. During transient loading conditions (startup and shutdown processes) in particular, 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 a basic cause 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 special types of blade roots to allow inspection of the most stressed blade roots 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 opening the turbine. The examination system had to provide reliable and reproducible results while remaining cost effective.

Extensive theoretical investigations had to be performed before any decisions could be made regarding selection of the ultrasonic examination technique. Reference reflectors were introduced into the calibration blocks at the most-highly-stressed areas. These areas were defined by Siemens Engineering. Using identical blades for the development of the UT inspection technique revealed information about detectability across all serrations of the blade roots to be inspected.

![Phased array UT inspection of turbine blade roots](image)

*Fig. 1: Phased array UT inspection of turbine blade roots*

Once the investigations on the calibration block had confirmed the suitability of the selected inspection technique for the problem in hand, a contoured probe and a tailor-made encoder-
The gaps in the volumetric examination which occur as a result have to be covered as far as possible by selecting axial scanning components. Examination of a shaft is performed in a number of stages (paths). Each stage consists of a complete rotation of the shaft and the associated scanning to record data from 0° through 360°. The scanning density around the
circumference of the shaft, i.e. the number of "shots'', is determined on the basis of the search unit sound field (6 dB sensitivity range) and the examination area (core area, boundary area, etc.). The axial spacing of the scanning paths and the axial scanning component itself are selected so as to ensure overlap of the 6 dB sensitivity range of the sound field in the examination area. The phased array UT technology supports efficient UT volumetric inspection of fully bladed turbine rotors.

Fig. 2: UT inspection of a fully bladed LP turbine rotor in the power plant

2.2.2 New Technology for UT Rotor Requalification

When inspecting the volume of turbine shafts, the required test sensitivity can only be achieved by removing numerous seal strips. This is to allow proper coupling of the ultrasonic probe to the examination surface of the turbine shaft via a couplant when using UT contact techniques. Test sensitivity is compromised when testing across seal strip grooves and this must be considered when setting the sensitivity of the examination system. The removal of seal strips for UT volume testing and their replacement after testing represent one of the major cost factors. Where testing requires that seal strips over between 200 and 300 m have to be replaced, this can result in considerable costs.

In order to save on such costs, the Siemens Energy NDT laboratory in Mülheim in Germany developed a testing technique which allows ultrasonic testing of fully-bladed turbine rotors, without having to remove seal strips between the blades or in the area of the shaft glands. Comprehensive investigations were performed on a bladed HP turbine shaft complete with seal strips to provide realistic conditions. Using the phased-array UT technique it was possible to develop a testing technique which allows the ultrasonic beam to be introduced over installed seal strips without suffering significant losses in test sensitivity. This was confirmed
in comprehensive tests. The technique developed has made it possible to significantly reduce the costs of UT requalifications while maintaining the quality of testing. The newly-developed UT technique for requalification of turbine shafts was used successfully for the first time in December 2013 on 2 turbine shafts in the Siemens workshop in Essen. Further contracts have already been received for a large-scale turbine overhaul in Africa scheduled for April 2014.

![UT Phased Array Inspection of a HP Turbine Rotor with installed seal strips in the Siemens Workshop in Essen / Germany](image)

**Fig. 3: UT Phased Array Inspection of a HP Turbine Rotor with installed seal strips in the Siemens Workshop in Essen / Germany**

### 3 In-service Inspection of Generator Retaining Rings

Rotor retaining rings are the components of turbine generators that are subjected to the highest stress. SIEMENS Energy Service Division has many years of experience in performing ultrasonic examinations on shrink-fitted rotor retaining rings in measures aimed at preventing retaining ring damage due to stress-corrosion cracking (VDEW – AA publication, 1993). Before the mid-80's, generator rotor retaining rings were manufactured in the material 18Mn5Cr. Field service degradation of 18Mn5Cr material has resulted in stress corrosion cracking (SCC) being the predominant failure mechanism. In view of this, periodic in-service inspection of rings or replacement of rings with stress corrosion resistant material made of 18Mn18Cr material was recommended by the OEMs. By the mid-90's most 18Mn5Cr rings had been replaced with 18Mn18Cr rings.
3.1 Experience with Different Inspection Techniques

SIEMENS Energy, Service Division carries out ultrasonic examinations on rotor retaining rings in the shrunk-on condition. This ensures that the shrinkage stresses are maintained in the component, and enables reliable detection of any incipient cracks in the shrink fit.

The so-called “corner reflection” search technique is used, whereby the shrink fit is scanned such that the ultrasound impinges on the inside surface of the rotor retaining ring at an angle of approximately 45°. This search technique enables reliable detection of any incipient cracks in the shrink fit.

Experience has shown that this inspection technique enables reliable detection of the smallest material flaws. The corner reflection technique allows both circumferential (cw and ccw) and axial (GE and TE) scans to be performed, thereby ensuring reliable detection of indications exhibiting all possible orientations. Experience gained by SIEMENS Energy Service Division shows that scanning from a number of directions is a prerequisite for detection of extremely small material flaws in the shrink fit. If indications are found during an inspection using this search technique, further analytical techniques are available to determine the extent of the indications (determination of crack depth/indication length).

3.2 Requirement for a new Inspection Technique

Since 1996, a mechanized system has been available for inspection of rotor retaining rings. This system offers the following advantages in comparison with manual ultrasonic examination:

- Full data recording capability enables data archiving and comparison of test results with in-service inspections.
- Inspection reliability is significantly increased in comparison with manual techniques, as mechanized performance largely excludes subjective influences which could potentially influence the inspection result.
- In the case of geometric indications in the shrink fit (due to slot wedges and rotor teeth), mechanized ultrasonic examination exclusively offers the possibility of clearly distinguishing between geometric indications and actual crack indications.
- Mechanized ultrasonic examination enjoys a good level of acceptance with independent inspection agencies and insurers, as the technique enables all data
relevant to the inspection to be recorded and utilized for subsequent analysis at any time.

However, while the 18Mn-18Cr alloy has not exhibited a longer term fracture mode, there have been some unique cases where cracking in service has been observed. In these cases, cracking has occurred under conditions outside normal design limits.

The power generation industry is moving towards longer intervals between “rotor out” maintenance outages, so the inspection of retaining rings should be performed after 10…12 years or more.

To ensure the reliable operation of generator rotors, advanced non-destructive examination techniques for the inspection of retaining rings are required. Siemens Energy has developed a state-of-the-art, combined, automated UT, ET & VT Inspection system, which supports in-situ inspection (rotor in place) as well as inspection when the rotor is out of the stator. This inspection system was developed in close co-operation between the NDT teams of Siemens Energy located in US, UK and Germany. It was based on the qualification of a combined UT and ET inspection technique for a real retaining ring. According to the instructions of Siemens Generator Engineering, several artificial flaws were made in all critical areas of the real retaining ring. After manufacturing of a mandril (disk with geometrical features of the generator rotor to simulate the influence of the rotor teeth on the UT result) the mandril was shrunk in the retaining ring. So an extensive qualification process of the UT technique was performed. All artificial flaws were detected. The trials were performed by NDT experts from Siemens Pittsburgh; Siemens Newcastle (UK) as well as Siemens Mülheim. In result of the qualification process an advanced UT, ET and VT inspection system was developed, which already is in use in Generator Service. The in-situ inspection reduces outage time, because there is no longer any need to remove the rotor from stator for the inspection.

Fig. 4: In-situ retaining ring inspection
4 Conclusion

These three examples of advanced inspection techniques demonstrate that direct customer benefits can be delivered through the use of problem-focused techniques. Key examples include time savings for component disassembly and reassembly required with conventional crack inspection techniques, but eliminated when advanced techniques are used. Given the requirement for virtually non-stop power plant availability and the associated reduction in plant downtimes, these kinds of in-situ service techniques are playing an increasingly important role in the planning and execution of plant outages.
5 References

Advanced NDE Inspection Methods for Field Service at Power Plants; Conference

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Options for management of retaining ring inspection): technical magazine
6 Disclaimer

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