18th Conference of the Electric Power Supply Industry (CEPSI)
October 24 - 28; 2010
Taipei (Taiwan)

Advanced ultrasonic applications for the inspection of turbine components

Michael Clossen*, Dr. Michael Opheys*, Hans Rauschenbach*, Michael Siegel*,

1) Abstract

Today worldwide a large number of Power Plants have already reached or exceeded their design life and therefore exhibit degraded 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 damage to components and has probably already been 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 has therefore gained considerably in 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 fulfill the prerequisites of the service- NDE on power plants.

The paper describes several advanced inspection techniques, which ensure the reliable inspection of turbine components during outages.

2. Nondestructive Examination in Turbine Service

Nondestructive examinations are among the most important activities during inspections of gas or steam turbines. These examinations are specifically performed on highly-stressed turbine components in order to detect damage which may have developed due to operating loading and to initiate appropriate measures (repair, replacement or limited release of components) in a timely fashion.
Conventional surface crack examination methods (dye penetrant examination, magnetic powder examination, eddy current examination) as well as volume examination methods (ultrasonic examination, radiographic examination) are implemented in inspections of both gas turbines as well as steam turbines. In recent years, especially those modern examination methods have increased in importance which are capable of ensuring reliable examination with no extensive disassembly work.

Modern ultrasonic examination methods (phased-array, TOFD in combination with modern manipulation methods) are especially suited for this purpose. Examples are described below to illustrate how long-term availability / reliable operation of the gas or steam turbine can be ensured by the use of modern nondestructive examination methods.

3. Nondestructive Examination of Gas Turbine Components as a Means of Service Life Extension of Highly Loaded Turbine Components

Because of the high stresses imposed on turbine and compressor components, gas turbines necessitate strict compliance with the specified inspection intervals. Siemens Energy has developed a concept which specifies a detailed examination scope at defined intervals for all components subjected to severe stress. The examination scope is based on the number of operating hours or turbine starts.

After the achievement of 100,000 operating hours a major turbine inspection is planned for life time extension of the rotating turbine components (tie bolt, disks, intermediate shaft). During this so-called LTE (Life Time Extension) inspection, all of the forgings are subjected to requalification. This requires that the gas turbine rotor be removed to enable access to all of the gas turbine and compressor disks for the recommended surface crack and ultrasonic examinations. The purpose of this requalification is to verify that the rotating components of the turbine do not exhibit any defects in the most highly-stressed areas which could affect reliable further operation of the turbine. As the gas turbine and compressor disks to be investigated have to be examined over the entire contour (and in some cases bladed), there was a demand for a portable examination system which enables investigation of the most highly-stressed areas of gas turbine and compressor disks with a high degree of examination sensitivity.

The basis for the nondestructive examination of turbine components is knowledge of the areas in which possible damage can be anticipated as well as the defect orientation relevant to stress. For the case of the gas turbine disks to be investigated, the area relevant to stress is in the immediate vicinity of the hub bore. Under consideration of all of the examination conditions, it was decided to develop an automated UT examination system which enables highly sensitive examination of the volume of the gas turbine disks close to the bore. This examination system is designed such that gas turbine disks can be examined with no further aids following unstacking of the turbine rotor. The two-axis manipulator is placed on the disk which has been set down on the floor. Ultrasonic examination of the area close to the bore is performed from the hub bore surface of the disk using highly sensitive probes with various beam angles.

Fig. 1: Examination system for automated UT examination of gas turbine disks

Because of the geometric conditions (examination of bore surface) and the defect orientation relevant to stressing (radial / axial defect orientation), examination from the hub bore serves exclusively for the detection of defects in the volume close to the bore. Determination of the radial through-thickness dimension of a detected reflector is not possible for geometric reasons. However, information on the radial/axial through-thickness dimension of defects in the highly-stressed area of the gas turbine or compressor disk is essential for a fracture mechanics analysis of detected indications (and thus for inferences regarding the allowability of detected indications).

In addition to the existing automated examination system for the ultrasonic examination of turbine and compressor disks, an analysis scanner was therefore developed which is capable of investigating the radial/axial dimension of indications detected in UT examination from the hub bore.

The basis for an analysis of the indications detected during examination from the hub bore was the calculation of scanning positions from the face of the wheel disk. Siemens Energy has developed a program for this which, in addition to individual input of the wheel disk contour, also enables the calculation of scanning positions for the analysis scanner. The objective is radial/tangential scanning from the face of the wheel disk in order to target the detected indications with the sound beam normal to the critical defect orientation (radial-axial). This enables determination of the maximum reflectivity for straight-beam scanning on the defect orientation relevant to stress. The indications are evaluated by the DGS method. Specific factors are applied to the detected reflectivities to determine the reference reflector size.

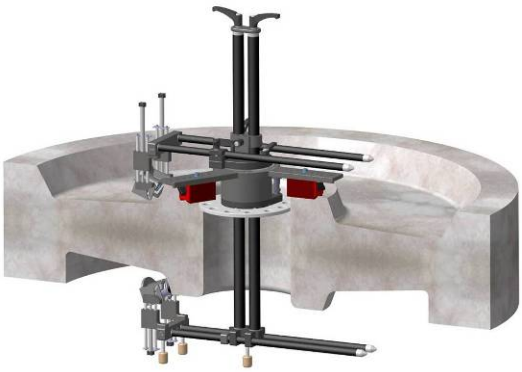

Fig. 2: Analysis scanner for gas turbine disks

This procedure enables determination of the essential information for the fracture mechanics analysis / safety analysis and thus for evaluation of the remaining service life of the turbine disks.

The development of the analysis scanner provides a flexibly applicable and efficient examination system for turbine service in connection with the automated examination system for UT examination of the disks. This has been confirmed by results from approx. 30 deployments worldwide.

4. Automated Nondestructive Examination Methods in Steam Turbine Service

Nondestructive examination is extremely important in both gas turbine and steam turbine service for the examination of highly -stressedrotating components during major turbine inspections which may be performed at intervals of 8 to 12 years. The examination of shrink-fit turbine disks from LP turbine shafts is taken as an example to illustrate how even turbine components of unfavorable design from an examination perspective can be reliably examined for defects relevant to loading by using high-performance examination systems.

LP turbine shafts are produced by means including shrink fit technology. Disks are shrink-fitted on a spindle shaft, with the turbine blades accommodated in the shrink-fit wheel disks. The following areas of the wheel disk are subject to especially high stresses under operating conditions:

- The entire shrink fit seat area (hub inner surface of wheel disk)

- Keyways
- Axial antirotation holes

The different techniques which can be deployed in ultrasonic examination are as follows:

- Angle beam scanning with normal incidence on the reflector:
  This technique is particularly suitable for detecting flaws on the hub inner surface and in the anti-rotation device holes. Shear waves are introduced into the turbine disk such as to hit the backwall (hub inside surface) at a tangent thereby providing normal incidence on reflectors that are oriented in an axial-radial direction.

- Angle beam scanning exploiting corner effect
  This very sensitive flaw detection technique introduces shear waves into the turbine disk such as to provide a 45° angle of incidence on reflectors that are oriented in an axial-radial direction in the backwall area.

- Straight-beam scanning:
  Reflectors detected using the angle beam methods mentioned above are then examined using straight-beam scanning with high-frequency longitudinal waves to determine the through-thickness size of the reflectors. In the case of a branched stress corrosion crack, an indication is received from the crack tip area in advance of the backwall echo.

- Time-of-Flight Diffraction (TOFD) Technique:
  To determine the through-thickness size of cracks in turbine disks, detected reflectors are investigated using two search units in V transmission. The two search units are positioned such that the angle of incidence on the backwall is 45° causing the beam to be reflected back to the receiver. In the case of a branched stress corrosion crack, an indication is received from the crack tip area in advance of the backwall echo from the hub inner surface. This mechanized inspection technique is the only reliable means of detecting small cracks in the center zone of a shrunk-on turbine disk, since detection of cracks oriented in a radial-axial direction using manual UT examination from one side of the disk is not possible due to loss-of-sensitivity caused by defect inclination.

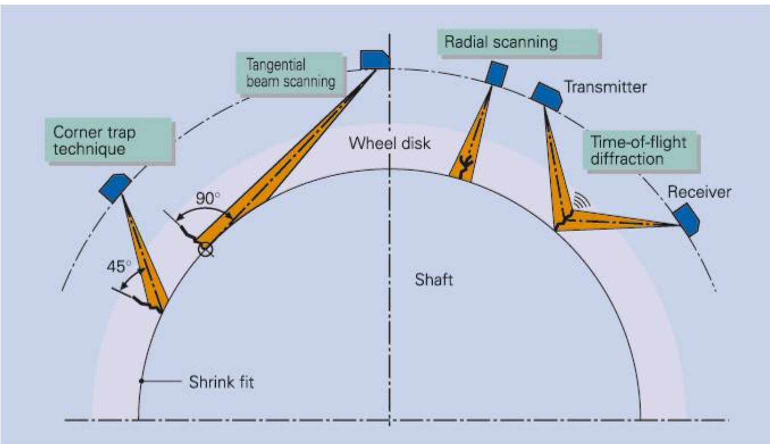

Fig. 3: UT examination methods for the examination of shrink-fit wheel disks

As the implementation of the above design features differs depending on the turbine manufacturer, the examination method must accommodate these differences. The capabilities of modern examination systems for turbine service will be described for the example of UT wheel disk examination on a 120 MW and a 500 MW LP turbine shaft (Parsons design).

Siemens Energy was contracted with the major inspection of a 120 MW steam turbine in early 2010. Ultrasonic examination of the shrink-fit turbine wheel disks was to be performed on the LP turbine shaft (year of construction: 1976). The unusual feature here was that shrink-fit turbine wheel disks #1 and # 2 were designed such that the disks are in contact at the wheel disk head. A gap of 32 mm was cut between disk #1 and disk #2 (generator end and turbine end) in order to make the faces of the wheel disks accessible for ultrasonic examination. Access to the disks for ultrasonic examination was extremely limited due to the design of the wheel disks and the dimensions of the disks.

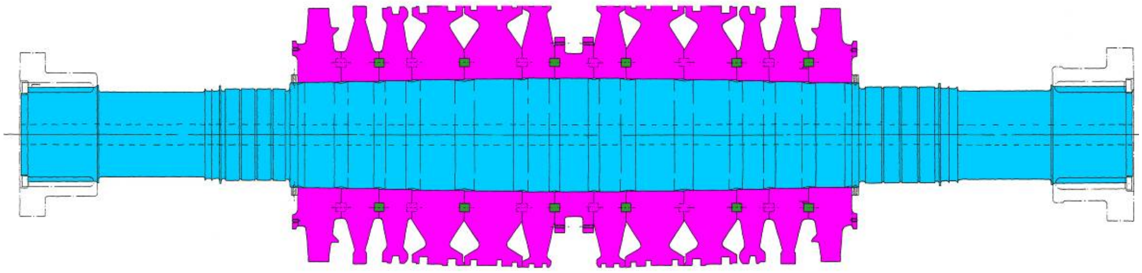

Fig. 4: LP turbine shaft with shrink-fit turbine wheel disks (Parsons design)

In addition to the problem of accessibility, it was also required that the axial antirotation holes in which pins engage in a hole in the adjacent disk be examined for cracks around the entire circumference of the antirotation hole. This examination was successfully performed on the 120 MW turbine shaft using a 7-axis manipulator specially developed for UT examination of shrink-fit turbine shafts. Both the conventional ultrasonic methods described above as well as phased-array technology for examination of the antirotation holes were used in the examination. The modern computer-supported 7-axis manipulator enabled examination under extremely restricted conditions. It was thus possible to verify that the 120 MW turbine shaft exhibited absolutely no cracks in the highly-stressed areas of the wheel disks even after 34 years of operation.

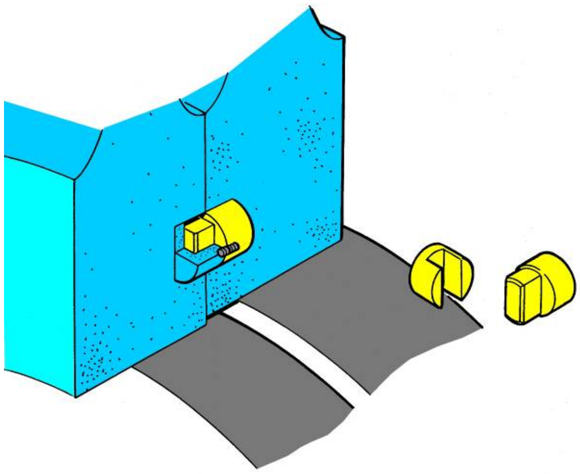

Fig. 5: Antirotation hole in shrink-fit turbine wheel disks

Analogous requirements for the examination were posed in the automated ultrasonic examination of a 500 MW LP turbine shaft (year of construction: 1974) in the summer of 2010. In this examination, an indication was found in area of expected indications was usingradial/tangential scanning. An indication was detected in the area of the antirotation hole on a beam path exactly in the center of the antirotation hole. This indicated a crack at the 6:00 o'clock or 12:00 o'clock position on the circumference of the hole. A phased-array examination of the antirotation hole from the wheel disk shoulder enabled a check of the upper 180° around the circumference of the antirotation hole (9:00 o'clock to 3 o'clock position). No indications were confirmed in this area. The crack could thus only be in the 6:00 o'clock position, but this is only accessible for ultrasonic examination by radial/tangential scanning. The phased-array ultrasonic examination method was used to confirm the information obtained by radial/tangential scanning. The results of this examination revealed unambiguous localization of the detected indications. An indication at the 06:00 o'clock position was clearly detected, which then had to be evaluated by Engineering. Further steps were decided upon in cooperation with the customer.

Fig. 6: Automated UT wheel disk examination of a 120 MW LP turbine shaft

5. Summary

The examples described in this article are intended to describe the requirements for modern nondestructive examination methods in turbine service. Conditions for nondestructive examination methods must be accounted for in the development of new methods in both gas turbine and steam turbine service:

- Automated examination systems which require the least possible disassembly work
- High examination sensitivity and reliable examination results
- Detailed examination results for the loading relevant to the part
- Reproducible examination results
- Data storage to enable comparison of the examination results in repeat examinations
- State-of-the-art examination methods.

If these criteria are fulfilled, nondestructive examination can also be effectively performed during short outages. The described solutions for the nondestructive examination of gas turbine disks as well as shrink-fit steam turbine wheel disks demonstrates effective synergy through the application of results obtained in turbine service to develop optimum examination methods for turbine service.

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