NDE AND MATERIAL EVALUATION FOR LIFETIME ASSESSMENT OF POWER PLANT COMPONENTS

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Abstract

In recent years there has been a strong push from electric utilities to assess the condition of their power generating equipment beyond the usual inspection for fitness. This push has mainly been to evaluate the condition of the equipment as it remains in service at or beyond its designed life. This push has been further reinforced due to the global economic conditions as some plant operators may continue to maintain and operate installed units instead of adding new installed capacity. To perform the condition evaluation and subsequently the lifetime assessment, a combination of Non-Destructive Evaluation (NDE) and material evaluations are needed. A combination of these evaluations can provide information that is needed to evaluate the presence of flaws in components, assess their lifetime, and with proper engineering analyses, sometimes provide an estimate of component remaining life. This cycle of evaluation can help provide plant operators the ability to continue the operation of their equipment in a prudent manner beyond the originally designed life. This paper discusses a variety of NDE techniques and methods that are used in the process of lifetime assessment. While the discussion contained herein is mainly limited to new advances in a variety of techniques it does not imply that the traditional methods (such as PT, MT) are not equally important in the NDE of these components. Additionally, the paper discusses the material evaluation methods that are used to estimate the remaining life of the components. These methods involve the evaluation of microstructure of components as well as analysis of other non-destructive tests such as hardness testing.

1. Introduction

Steam turbines are generally designed for reliable operation for a finite life. Many older units have exceeded their anticipated design life objective. Many turbine components are made of steels with addition of different alloying elements such as chromium, vanadium, nickel, molybdenum, titanium etc. During operation, these materials can undergo different metallurgical degradation processes due to high stress, creep, fatigue etc. So, a lifetime assessment of these components is essential if an owner is interested in continuing reliable operation of the units [1].

Several factors can affect the lifetime of the turbine components. Among the factors that determine the lifetime are the strength and reliability of components that are exposed to high temperatures and pressures. As the component goes into operation, several different degradation mechanisms can limit the remaining life of the service components. The most common potential degradation mechanisms in the materials of turbine components are creep, high cycle and low cycle fatigue, corrosion, and material aging. A majority of the turbine components are exposed to high temperatures and high stress conditions during operation as well as during start up and shut down. As a result, these components go through cyclic thermal and mechanical loading which can lead to creep and fatigue. For some low pressure turbines moisture exposure coupled with high stresses can lead to stress corrosion cracking.

2. Application of LTA

Lifetime assessment is performed on all the stationary and rotating components on the turbine. Generally the lifetime assessment is divided in to two broader categories based on the component and their service conditions (See Figure 1).

- Condition assessment
- Remaining Lifetime Assessment

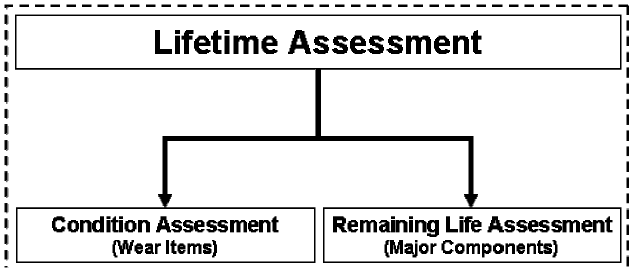

Figure 1 Lifetime Assessment overview.

For some components, condition assessment may be sufficient. This is generally true for components that operate at lower temperatures and smaller components that are more readily replaceable (wear items). Other components may require a remaining lifetime estimate. Remaining lifetime of components is estimated by a combination of NDE testing, materials inspection, and engineering analyses in conjunction with operational data.

Components that are typically inspected for condition assessment may include: Bearings, bearing housings, pedestals, turning gear systems, blades, LP rotor, and bolts.

Components that are typically inspected for remaining life estimate include: HP/IP casings, HP/IP throttle and governor valves and valve bodies, main steam pipe lines, and HP/IP rotors.

3. LTA Methodology

Lifetime assessment of power plant components involves a variety of approaches to obtain comprehensive knowledge of the service component condition. The main tools available are:

a. Nondestructive Evaluation
b. Metallurgical Evaluation
c. Computational Methods

3.1 Nondestructive Evaluation (NDE) Methods:

NDE is a well established and proven tool to help determine the integrity of steam turbine, generator, and gas turbine components during their life-cycle in power plant environments. Conventional methods such as penetrant testing (PT) and magnetic particle testing (MT) are well suited to detect surface and slightly subsurface discontinuities. These methods are particularly sensitive to small surface service induced cracking in various components. Penetrant testing, which requires the discontinuity to be open to the surface for detection and magnetic particle testing can only be used on magnetic materials. Visual testing (VT), performed either with the human eye or with high-resolution cameras, is limited to dimensional measurements, usually the detection of large open discontinuities or component condition assessment. Longitudinal and shear wave ultrasonic testing (UT) is used for full volumetric interrogation of a component while eddy current testing (ET), an electromagnetic method, is sensitive to small surface or slightly subsurface indications in many materials. Radiography testing (RT), using X-rays or gamma rays is useful for detecting internal indications in welds, pipes, and a host of other components.

Figure 2: PT and MT being performed on a Steam Turbine unit.

In addition to the conventional methods of NDE, Siemens has developed specialized methods to provide improved inspection capabilities and better results that assist in the LTA and Life Time Extension process. Some of these methods are discussed below:

3.1.1 Ultrasonic Phased Array

Siemens continues to develop ultrasonic phased array techniques to reduce inspection times and improve data evaluation for a variety of turbine components. These techniques include methods for inspecting Westinghouse design Low Pressure steam turbine disc bores and other manufacturer design disc bores. To assess the condition of the blade roots, techniques have been developed that allow the highly-stressed areas of the blade root to be inspected in situ. Similarly, phased array methods are in place to detect stress corrosion damage in blade attachments while the blades are installed in the turbine disc (in-situ examination) [3].

It is extremely important that the inspection methods that are developed accurately address the requirements of the ultrasonic examination. To fulfill this need the inspection process is modeled using a variety of methods and is then tested and validated. These methods must include the modeling of the inspection component geometry and phased array energy to develop accurate control (focal) laws. In addition, the methods must include means of determining the behavior of the incident beam as well as the behavior of the reflected beam [4]. The modeling of the beam is even more critical when dealing with a compound curvature considering the effect the surface has on the sound beam. In the case of a continuously changing surface with complex geometry, there are instances when the curvature is positive in one direction and negative in another. This affects

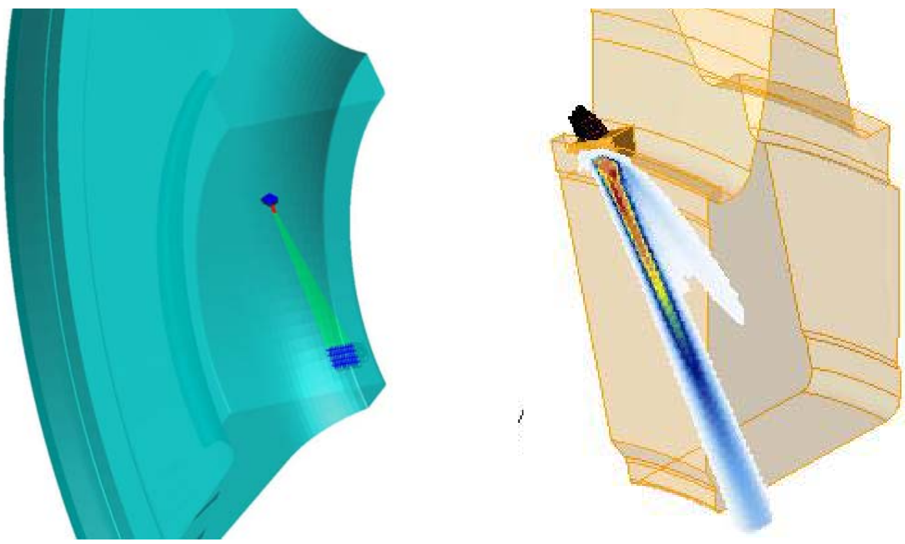

Figure 3: Focal Law simulation on a Disc Bore

the sound beam differently and has to be modeled to get a sensible and accurate set of focal laws for an examination.

Developing accurate focal laws is the first step in formulating a technically sound inspection methodology. The next step is determining the sound field that is transmitted and verifying that it is available at the area of interest. This is done by simulating the field of the beam at the focal depth and determining the quality of the sound that is available for reflection. Based on this information important decisions can be made regarding the scanning strategy of the area of interest. It is also important to determine the quality of the signal received back at the transducer from the area of interest. There are various methods of accomplishing this. A traditional method is testing this experimentally and evaluating the complete exam on test specimens. While this method is ideal, it may not be a feasible or realistic method for reasons ranging from availability of sample specimens to the time and cost involved. Another approach is the accurate simulation of the examination and then analysis of the results. This provides enough information to devise a scan strategy with the confidence that the results obtained are meaningful and reliable.

Figure 3 illustrates the simulation of focal laws on blade attachments and disc bores respectively. The laws are developed using a CAD model so it is representative of a true 3D space. No matter what the application, when dealing with complex geometry, simulation of laws provides a valuable mechanism for determining the accuracy of the laws and provides feedback to optimize the scans. Further, once the focal laws are developed for a desired scan, analysis is required on the beam properties to verify the validity of the focal laws. The field diagram provides information about the sensitivity of the sound beam at the focal point and is a feedback tool for the user to vary the scan strategy. The authors consider these modeling and simulation tools of prime importance in establishing sound and thorough inspection methods.

3.1.2 Rotor Bore Inspections

Many units in service have rotating equipment (rotors) that have bores in them. These rotors were manufactured in an era when forging techniques were not as sophisticated as today's methods and which sometimes may have resulted in impurities and inclusions migrating towards the center during the forging process. The response to address these imperfections at that time was to machine a bore through the center to remove centerline impurities and to help minimize the chance of crack initiation that had the potential of contributing to a rotor failure. While this was considered an effective approach, it did not address the potential for an area around the bore which might include some discontinuities linking together as a result of service operation. Inspections can be performed on the bore surface, near surface, and deep surface for indications of these discontinuties. These inspections can include a variety of methods including magnetic particle testing, eddy current testing, and ultrasonic testing.

These inspections are performed to detect cracking from service stress as a result of forging discontinuities. Often, a mechanical test to measure the bore diameter is performed. Accurate bore measurements can be used to help detect the presence of creep damage. In addition, either eddy current inspection of the bore surface or magnetic particle inspection is performed. For sub-surface indications, multi-channel ultrasonic inspection is performed. To perform the eddy current and the ultrasonic inspection, sophisticated automated scanning systems developed by Siemens are used. These systems provide information regarding the location of the

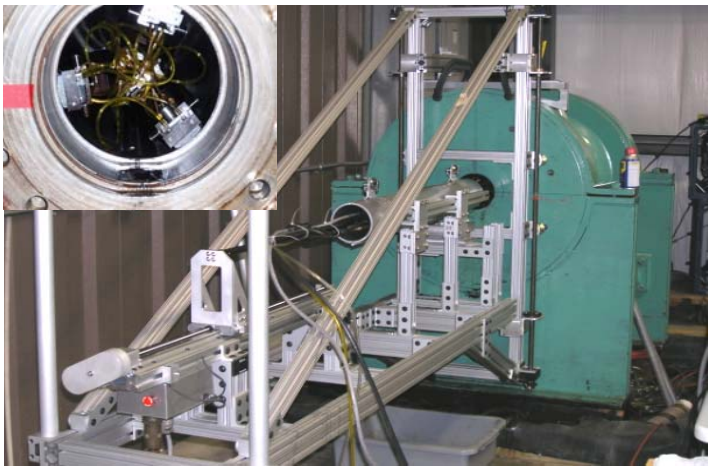

Figure 4: Rotor Bore inspection scanner testing on a calibration rotor.

discontinuity while the inspection method provides information related to the discontinuity itself. The data collected is then analyzed to determine the rotor condition. The data is further used, in conjunction with other information, to estimate the remaining life of the rotor. This can help many plant operators to keep equipment operational in a cost-effective manner. The scanning systems (Figure 4) play an essential role in the successful application of this inspection. The ability to control the various parameters such as scanning increments, data resolution, provides flexibility to the inspector.

3.2 Metallurgical Evaluation

During operation, some highly stressed components of steam turbine power plants can undergo a change or "creep" in material properties due to cyclic stress and exposure to different temperatures. There are several metallographic techniques that have been developed to evaluate creep distress by using the correlation of microstructure of the original material to the serviced material and also by using hardness measurements. In addition to creep distress there are other forms of materials degradation that can also reduce the life of the materials. There are a variety of materials investigation techniques applies for the lifetime assessments.

Material investigation can include one or more of the following methods:

- Replica of Structure
- Hardness Test
- Mechanical Properties
- Chemical Composition
- Material Sampling (Boat/Scoop)

Replication method: Materials exposed at high temperature show a change in the microstructure by forming a void at the grain boundaries or evolution of carbides at the grain boundary. Investigation of formation of voids is a very common practice [in the European region] for evaluating creep. Creep distress starts by forming a void at the grain boundary and as the distress accumulates the cavities increase in size and gradually forms micro cracks and can eventually rupture. In steels, due to the presence of different elements, different carbides form due to exposure at higher temperature and these carbides can precipitate inter-granularly as well as intra-granularly. Also the carbides tend to increase in size as they are being exposed to high temperatures, eventually softening the materials. By taking a replica of the microstructure the creep distress can be evaluated. Figure 5 shows the replica method being performed on reheat valve bodies and the microstructure was taken from onsite microscope.

Figure 5: Material replication being performed on a reheat valve (left); replica image under microscope (right).

Hardness method: The hardness of any material is reduced as it undergoes different degradation modes caused by creep-fatigue as a result of high temperature exposure for a long period of time and high stress condition during start-ups and shut-downs. It was first proposed by Goldhoff et. al that hardness value can be used as a nondestructive method to evaluate creep distress. There is a correlation between the hardness values to the remaining creep life of any material. The hardness of materials changes with aging time, temperature, and stress, and as a result hardness decreases with exposure to creep (Figure 6). Thus, by measuring the hardness of any component it is possible to extract information that assists in estimating the remaining life of the component.

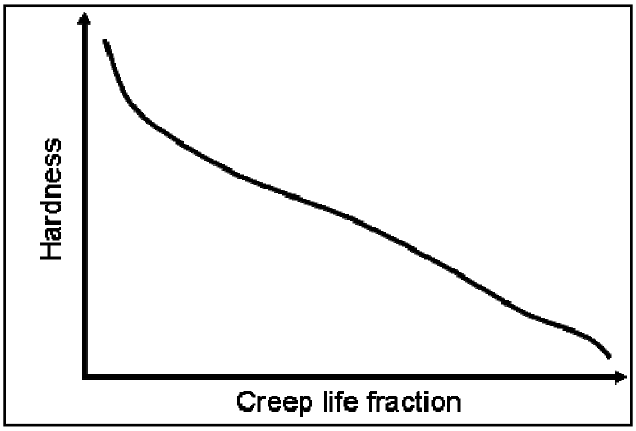

Figure 6: Remaining creep life fraction as a function of hardness value.

Mechanical Properties: In some cases a piece of material is extracted form the turbine component to check the mechanical properties such as yield strength, ultimate tensile strength, elongation, fracture toughness etc. This data helps in estimating the remaining life of the component/material.

Chemical Composition: Material information is a key tool for lifetime assessment of any component. If the material information can not be obtained, it is necessary to use different method to determine the chemical composition of the materials. This can be performed by using non-destructive (XRF) and destructive method.

Material Sampling (Boat/Scoop): If structural integrity of the component is really important and a real specimen is necessary, sometime a thin layer of material (scoop/boat) is removed to perform the assessment in the laboratory environment. Figure 7 is showing a Siemens designed tool (Patent Pending) to remove scoop sample. The laboratory analysis can give more detailed information regarding creep damage and any other form of material degradation.

Figure 7: Siemens scoop (boat) sample tool removing a sample from a gas turbine cylinder.

3.3 Computational Methods (FEA)

As mentioned before, not all the components may require analysis as part of lifetime assessment. Engineering analysis is performed on all major components that are subject to high temperatures and stresses to estimate remaining life. Steady state and non-steady state turbine operational data is used for lifetime analysis. Turbine components are operating in a temperature range where the creep mechanisms are under steady state stress and the material is exposed to thermal cyclic stresses as a result of transient operations. These combined creep and thermal stresses, which in turn are responsible for low-cycle fatigue over operational time are principal degradation mechanisms that can lead to crack initiation and growth. The critical factors for a meaningful component analysis are the basic design data and appropriate boundary conditions like thermal convection and radiation, mechanical restrains or contacts during operation.

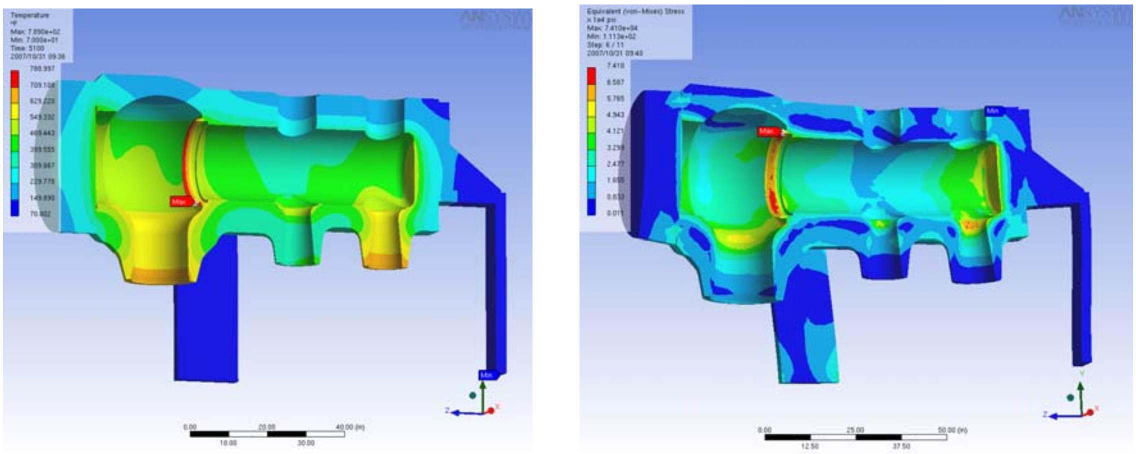

Figure 8: Temperature and stress distribution during a cold start on a Siemens design steam chest.

4. Summary

Due to the maturation of steam power plant components, lifetime assessment of the major components and the turbo-set is increasingly important. This assessment is further being aided by development of new methods using the latest technologies available for inspection.

The evolution of advanced NDE techniques plays a key role in making this assessment more comprehensive and making it feasible for power plant operators. Evaluations performed using these methods can help these operators if they are interested in continued operation of older power plants in a prudent manner. These evaluations can not only provide information about the condition of the components but can also provide information that helps in the evaluation of the lifetime of these parts.

The material assessments provide information that is not provided by the NDE assessments and information that is generally not computable. This NDE and material information is then coupled with operating history and material history of the components provides the basis for the remaining lifetime estimates of major components.

A clear objective of the LTA process is to assist the user to evaluate the potential for continued operation of the power plant in a prudent manner and provide the possibility to detect and address potentially debilitating conditions before damage may occur.

This approach has been successfully implemented by Siemens at a variety of power plants across the globe.

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