ELECTRIC POWER
RESEARCH INSTITUTE

Integration of Component Stress Analysis with EPRI Steam Turbine Corrosion Modeling Software

1011937

Integration of Component Stress Analysis with EPRI Steam Turbine Corrosion Modeling Software

1011937

Technical Update, December, 2005

EPRI Project Manager

S. Hesler

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This document was prepared by

Electric Power Research Institute (EPRI)
1300 W.T. Harris Blvd.
Charlotte, NC 28262

Principal Investigator
S. Hesler

This document describes research sponsored by the Electric Power Research Institute (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

Integration of Component Stress Analysis with EPRI Steam Turbine Corrosion Modeling Software. EPRI, Palo Alto, CA: 2005. 1011937.

ABSTRACT

This technical update is one of a series of reports covering development of an analysis tool to predict the probability over time of corrosion-related damage in low-pressure steam turbines. This damage includes pitting, stress corrosion cracking, and corrosion-fatigue. Related EPRI reports 1004190 and 1009690 published in 2004 and 2005 describe development of a deterministic model based on Damage Function Analysis for predicting localized corrosion damage in LP steam turbine components. Report 1010184 issued in 2005 describe results of experiments that measured the kinetic (electrochemical) parameters for the steels of interest (403SS, A470/471, 17-4PH, and 20Kh13). The focus of this interim report is the integration of mechanical stress analysis capability with the existing Damage Function Analysis, which is the final step in producing a complete analysis program for use by the power industry. The resulting EPRI software will be benchmarked in 2006-7 against actual cases in which turbine components experienced corrosion damage. The report discusses the role of mechanical stress in the overall corrosion damage analysis scheme, and the options under consideration for generating stress information in the final software program.

ACKNOWLEDGMENTS

EPRI wishes to acknowledge Dr. George Engelhardt of OLI Systems, Inc. and Dr. Digby MacDonald of Penn State Center for Electrochemical Science and Technology for their ongoing research and development in support of the EPRI corrosion modeling algorithm.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Corrosion-related damage to low pressure (LP) steam turbine blades and disks is a leading cause of plant unavailability. The damage mechanisms include localized pitting, stress corrosion cracking (SCC) and corrosion fatigue (CF). These mechanisms interrelate, for example pitting is often the precursor to initiation of stress corrosion cracking in susceptible materials. Likewise, stress corrosion cracks could propagate through fatigue if vibratory stress levels are sufficient. Highly stressed turbine blade airfoils, root attachments, and their corresponding disk attachments are particularly vulnerable to CF and SCC. Considerable effort is expended performing inspections during maintenance outages to determine the condition of low pressure (LP) turbine components. If cracking is detected during periodic inspections, an assessment of failure risk is made using fracture mechanics analysis techniques. The situation often results in unplanned maintenance which is both costly and time consuming. Many plants have been forced to replace blades, disks, or entire rotors to minimize risk of unavailability. The cost to the industry is significant. Steam turbine manufacturers have made some progress addressing corrosion-related damage in modern replacement rotor designs, but the changes are incremental and the plant operators must still take steps to control the operational factors that contribute to rotor damage.

EPRI has initiated research on characterizing and predicting the corrosion process specific to materials in the phase transition zone (PTZ) of low pressure steam turbines [1, 2, 3]. This work has resulted in development of localized damage prediction algorithms and associated computer codes. Knowledge of the characteristics of early condensate, liquid films, and chloride concentrating mechanisms in the PTZ has been established based on a significant body of experimental research conducted over the past decade under the EPRI Strategic Science and Technology program [4]. This emerging damage prediction technology will fill a crucial need in the industry by allowing plants to understand and control the operational factors that contribute to corrosion-related damage. Plants can then extend the life of their LP rotors, improve availability and delay future capital expenditures.

The basis for EPRI's localized corrosion model is the Damage Function Analysis (DFA). DFA is based on the analogy between the growth of a corrosion defect and the movement of a particle. In this analogy, pit depth relative to the component surface over time is modeled as particle motion. DFA uses a system of differential equations that describe the distribution of corrosion events in terms of depth for a given observation time. These events include the pit nucleation, passivation, reactivation, SCC, and CF. DFA is a deterministic approach rather than a purely empirical approach, and is based on the fundamental equations governing corrosion pit behavior. DFA is coupled with extreme value statistics (ESV) estimate the worst damage and to extrapolate corrosion damage over long time periods using laboratory material test data obtained on small samples [3]. This is beneficial since the time needed for material testing to support a traditional empirical approach could not support timely completion of a model.

1.2 Objective

The EPRI LP steam turbine corrosion modeling software is planned for release in 2007. The software must in general be capable of predicting damage at all locations at risk on the rotor. Therefore, future implementation and practical use of EPRI's corrosion model by the industry will require that rotor component mechanical stress be evaluated at these locations. This report will describe details of the required stress information, potential sources for this data, and how it could be integrated with the DFA algorithms to produce the final software tool. The overall project objective is to produce a software tool for use in predicting LP turbine rotor damage, in which the evolution of pits to cracks and subsequent crack propagation is addressed in a single algorithm.

2 OVERVIEW OF CORROSION MODEL

This chapter will provide an overview of the EPRI corrosion model algorithm. As described in this report introduction, this algorithm is based on damage function analysis (DFA) and will be integrated with stress data, material data, and the evolutionary history of local environment to yield a probability of failure over time.

2.1 Damage Function Analysis

Chapter 2 of reference [1] provides a detailed description of damage function analysis. It will not be repeated in this report, however a general discussion is provided for completeness. The EPRI algorithm predicts the following characteristics of corrosion damage:

1. pit nucleation rate
2. pit propagation
3. pit repassivation
4. transition from pit to crack
5. growth of crack due to steady or cyclic mechanical stress

All five of the above processes are modeled in a completely integrated manner, using fundamental data on material corrosion specific to each alloy used on turbine rotor assemblies [3].

In the past, damage tolerance analysis (DTA) techniques were the only means available for assessing risk of failure in cases where cracks were detected in highly-stressed components in corrosive environments. DTA essentially combines linear elastic fracture mechanics with material properties obtained from tests in simulated environments to predict crack growth and critical crack size. The essential shortcoming of DTA is the inability to model crack initiation, which must therefore be addressed based on historical data or assumptions from industry experience. DFA addresses the shortcoming of DTA by including all aspects of pit formation and transition into cracks.

2.2 Analysis Flow Diagram

Figure 2-1 contains a flow diagram of the integrated analysis process used in the EPRI corrosion modeling software.

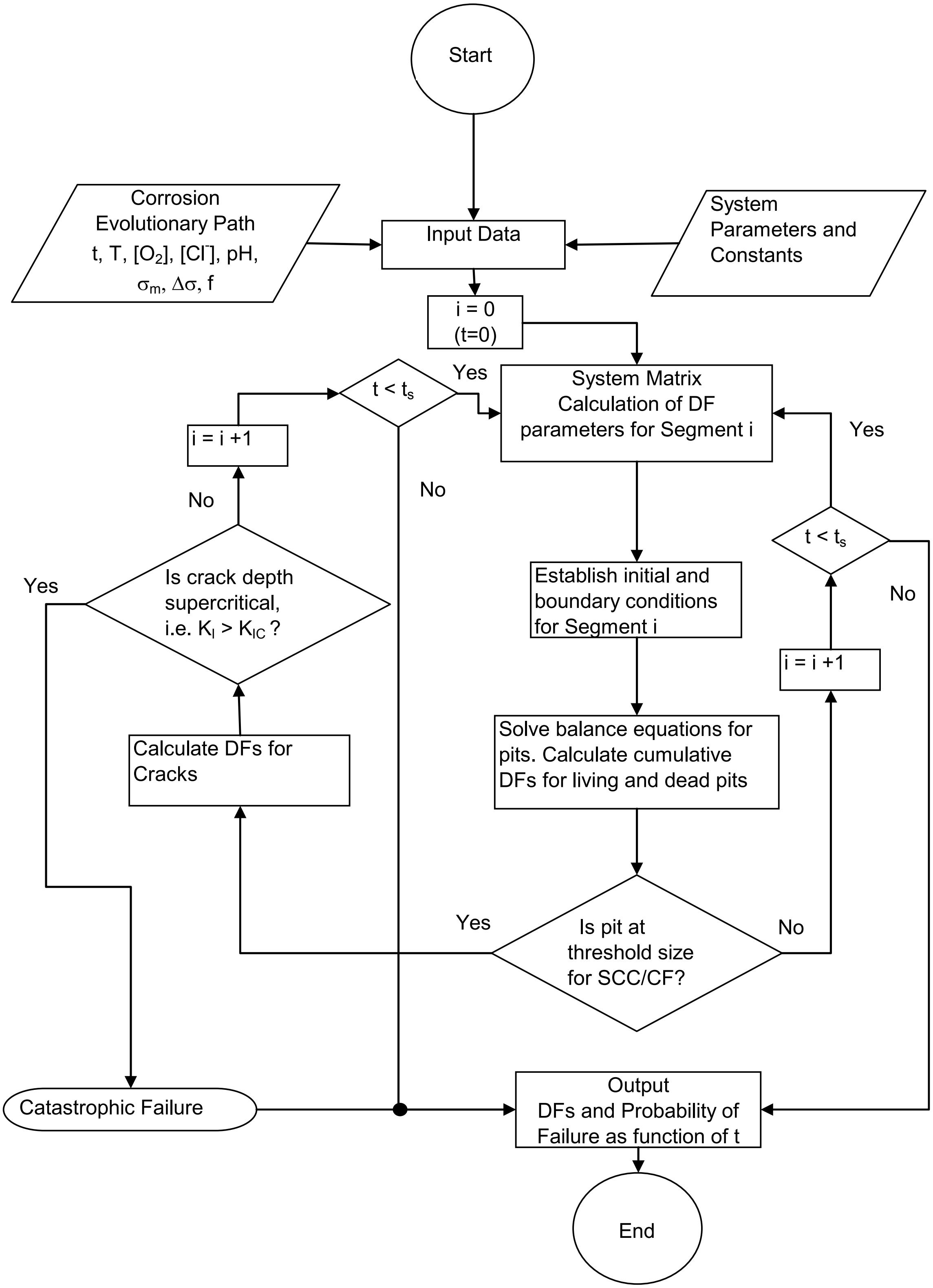

Figure 2-1 Flow diagram of integrated corrosion damage model for LP steam turbine rotors

The terminology used in Figure 2-1 is provided in Table 2-1 below.

Table 2-1 Terminology used in Figure 2-1

i	analysis time increment
t	time
T	temperature
$[O_2]$	oxygen concentration
[Cl]	chloride concentration
$_m$	mean mechanical stress
	alternating stress amplitude
f	alternating stress frequency
DF	damage function
t_s	desired service life of component
K_I	stress intensity
K_{IC}	critical stress intensity

In Figure 2-1, the block labeled *system parameters and constants* are essentially the time-independent material properties. The input block labeled *corrosion evolutionary path* contains all the time-dependent input parameters. The flowchart describes a complete analysis at one location on the steam turbine rotor, which in general will have a unique evolutionary path. The analysis starts at time zero assuming undamaged material. At each subsequent time increment, damage function analysis is performed to predict growth and concentration of pits. Implicit in this analysis is a determination of whether pits are active or passivated (i.e. no longer active).

At each time iteration, pit depth is compared to threshold crack depth for stress corrosion crack propagation (K_{ISCC}) or crack growth due to cyclic stress ($K_{I,th}$). If threshold crack depth has not been achieved, the analysis loops back to damage function analysis for pit formation/growth. This will continue until analysis time reaches the desired service life (end of simulation), or until a pit reaches threshold size. If pit depth reaches threshold size, the analysis diverts to a separate damage function analysis that combines both mechanical and corrosion-driven crack growth. In this second analysis loop, the crack is propagated over time, and may reach critical size (stress intensity equals critical stress intensity for material).

The process in Figure 2-1 will be applied over a range of turbine rotor locations for which a unique set of evolutionary path data and/or material electrochemical parameters is available. Differences in rotor blade and disk alloys, as well as differences in mean and alternating stress at various locations on the airfoil, blade root, and disk attachment will result in a need to analyze several locations when applying the scheme shown in Figure 2-1 for a single rotor analysis.

One of the most important operational aspects of the evolutionary path that must be carefully defined in preparing an analysis relates to turbine layup. During layup, oxygen concentrations will increase, which promotes the pitting process. Intervals and durations of turbine layups must be accurately reflected in the evolutionary path input file since a majority of the pitting damage occurs during these times. If condenser vacuum is maintained during the layup, damage is significantly reduced and that can be reflected in the oxygen concentration input. Defining time duration of turbine layup is important since rate of pit formation and growth is not linear over time.

From Figure 2-1, it is noted that stress data is first required for the assessment of threshold pit depth. Stress data is again needed as an input for the damage function analysis applied after the pit-to-crack transition during the crack growth phase. Finally, stress data is needed to establish the critical crack size (a_{cr}) and associated stress intensity.

3 STRESS ANALYSIS OF STEAM TURBINE COMPONENTS

This chapter will provide information on stress analysis is it relates to LP steam turbine components. A general discussion is provided, followed by identification of existing EPRI analysis tools. A brief discussion of commercial analysis tools will follow. Finally, the chapter will conclude with a discussion comparing the options available for generating stress data for EPRI's LP steam turbine software under development.

3.1 Key Considerations

Rotating components of LP steam turbines experience very high stress levels due to the large diameters of the blades and disks, and the high rotor speed. The thermodynamic requirement for a large flow area in the LP section is the fundamental reason for these factors. Inlet steam to fossil unit LP turbines is superheated, but the phase transition from steam to liquid occurs generally in the penultimate (L-1) stage nozzles. The L-1 rotating row and the final stage operate in two-phase flow, in which there are high concentrations of chlorides in the condensate and liquid film that coats the steam path components. In addition to the high concentration of chlorides in the concentrate, crevices between the blade root and steeples are features that trap chlorides due to capillary action. If the metal temperature in these crevices exceeds the saturation temperature, then condensate will boil off leaving the chlorides in the crevices and resulting in even higher concentrations. The result of this series of concentrating mechanisms deposit chlorides at the areas of high mechanical stress (blade roots and steeples) producing a high incidence of pitting, and cracking observed in the fleet of large steam turbines. The disk material, with relatively lower chromium levels, has experienced the most severe pitting damage and associated cracking.

Specific areas of LP steam turbine rotors for which corrosion damage has been observed include [5]:

1. blade airfoils
2. blade tenons/coverbands/tiewires
3. blade roots
4. disk steeples
5. disk faces
6. disk bores and keyways

In many of the above component areas, the local stress field features high nominal stress, with a superimposed stress concentration due to notches, fillets, transitions, etc. In the blade roots and steeples, the peak stress may exceed material yield strength resulting in plastic deformation.

In addition to the high mean stress, there can be significant alternating stress levels due to flow-induced vibration on the rotating blades. This vibration can occur at harmonics of the rotor speed due to aperiodic discharge flow exiting the fixed nozzles. In addition, vibration can occur due to aeroelastic instabilities associated with blade flutter or condensation shock. These conditions are rare, but when they occur the result is very high levels of alternating stress and resulting rapid accumulation of fatigue damage.

Accurately predicting mean and alternating stress levels in LP turbine components is a technical challenge. For over twenty years, the finite-element analysis (FEA) approach has been successfully used in predicting component operational stresses. Advances in computing speed have directly resulted in the ability to produce more refined models and improved definition of the local stress concentrations referred to above. Several root cause analyses of component failures over the past two decades has revealed that fatigue and stress corrosion cracking are the most common factors, and that high vibratory stresses is strongly related to the tuning of the blade frequencies away from harmonics of the rotor speed.

3.2 EPRI Analysis Tools

Two software programs have been developed by EPRI over the past twenty years that are used to model stresses or failure probabilities of key LP turbine components. These programs are BLADE-ST and LPRimLife.

3.2.1 BLADE-ST Software

The EPRI BLADE-ST FEA software tool began development over twenty years ago to address an increase in steam turbine blade failures and very high unit unavailability and repair costs [6]. BLADE-ST was successfully used in many root-cause failure investigations and design evaluations. In the early 1990s, several steam turbine OEMs licensed the software to use in new rotor design analyses.

BLADE-ST is a completely stand-alone code that included extensive preprocessing, mesh generation, steady and dynamic stress calculations, and postprocessing capabilites. Considerable development effort was required to create three-dimensional mesh generating routines to handle complex geometry associated with blade airfoils, roots, coverband/tenons, disk steeples, etc. A range of common domestic turbine blade designs were accommodated, each of which required a specialized mesh generation module to address their unique geometric characteristics.

The goal of developing BLADE-ST was to enable turbine engineers and analysts at the power generating companies to perform their own analyses, without requiring third-party assistance or need for a commercial FEA program. Changes in the utility industry in the mid-1990s reduced the number of specialized staff who could devote extensive time to performing FEA. This trend occurred in parallel with the appearance of a number of new blade design features; specifically attachment designs, tiewire designs, and coverband/shroud designs. These new features required costly development of specific mesh generation modules. The last factor that affected the viability of BLADE-ST was the change in PC operating systems in the mid-1990s that required programs to be converted to 32-bit applications. The combination of a shrinking user community, and increased costs for software support and maintenance resulted in a decision by EPRI's to discontinue support for this software tool. BLADE-ST is therefore no longer available for licensing.

The 16-bit DOS version of BLADE-ST is still available as a possible source of stress analysis subroutines for use in other software tools, such as the corrosion analysis tool currently under consideration. With this option, there would be costs associated with subroutine conversion to allow use with modern 32-bit processors. The core analysis capabilities included in BLADE-ST that could be used in future software tools include:

1. stiffness matrix generation and static stress analysis
2. Neuber's rule for estimating true local stress-strain in areas of high stress concentration at risk of fatigue crack initiation
3. gap elements for blade-disk contact surfaces
4. Guyan reduction routine, modal analysis
5. harmonic response calculation
6. transient response analysis using modal superposition
7. backsubstitution of modal, harmonic, and transient dynamic displacements to achieve full stress distribution

Use of the above modules would still require development and maintenance of a preprocessor and mesh generator appropriate for the rotor components of interest.

Fatigue crack initiation calculations are performed in BLADE-ST using the local strain approach, rainflow cycle counting, and Miner's rule. Using either a user-defined history of mean and alternating stress, or a projected future profile supplied by the user, a deterministic calculation of percent fatigue initiation life consumption is performed.

3.2.2 LPRimLife Software

EPRI's LPRimLife analysis code was developed in the late 1990s for the purpose of performing fracture mechanics and remaining life analyses of disk attachments subjected to stress corrosion cracking [7]. The following list describes the scope and attributes of LPRimLife:

1. Performs calculations on tangential-entry dovetail and axial-entry serrations
2. LPRimLife does <u>not</u> contain a stress analysis module; instead, a detailed two- and three-dimensional array of stress data produced by a separate stress analysis is imbedded in the software
3. The software addresses SCC only; not fatigue initiation or cyclic crack growth
4. The software uses standard crack models (corner, edge, semi-elliptical)
5. The program includes a probabilistic (Monte-Carlo) analysis of crack growth to critical size, accounting for uncertainty in the major factors such as growth rate, material toughness, crack depth at start of analysis
6. LPRimLife does not rigorously address SCC initiation

The result of an analysis using LPRimLife is a probability of failure vs. time, with failure defined as either reaching critical crack size or experiencing ductile failure of the remaining ligament.

These results are used to support run/repair/replace decisions following disk rim inspections in which stress corrosion cracks are detected. The analysis starts with an existing crack at a user-defined location,

LPRimLife can operate on current 32-bit operating systems, and has a graphical user interface. Because the analysis is geometry-specific and the mean stress data must be pre-generated and loaded into the software, a limited number of disk attachment configurations are available for analysis. New attachment geometries can be analyzed, but only after the necessary 3-dimensional stress data has be calculated and loaded into the program.

Figures 3-1 and 3-2 contain diagrams of the basic analysis process used in LPRimLife, and the Monte-Carlo simulation to determine failure probability.

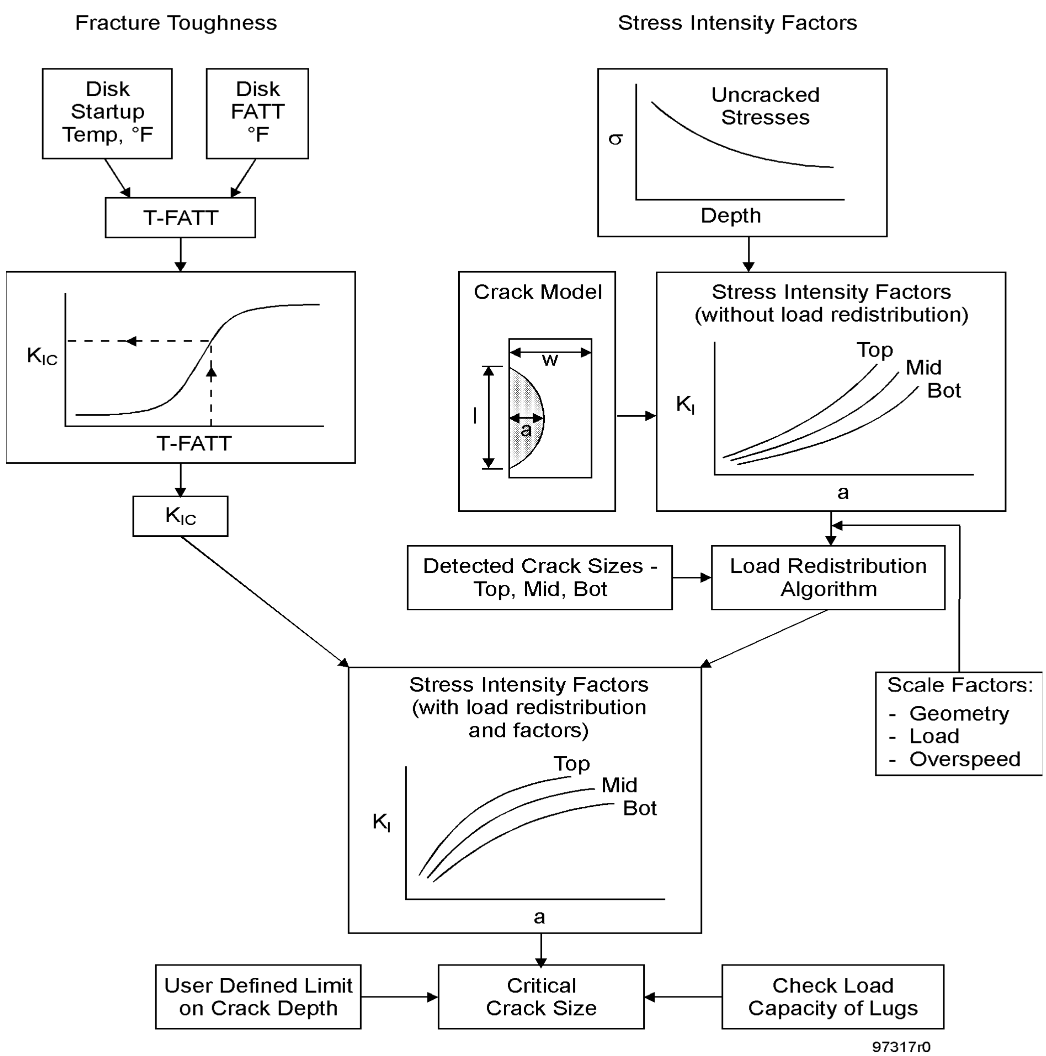

Figure 3-1 LPRimLife analysis process

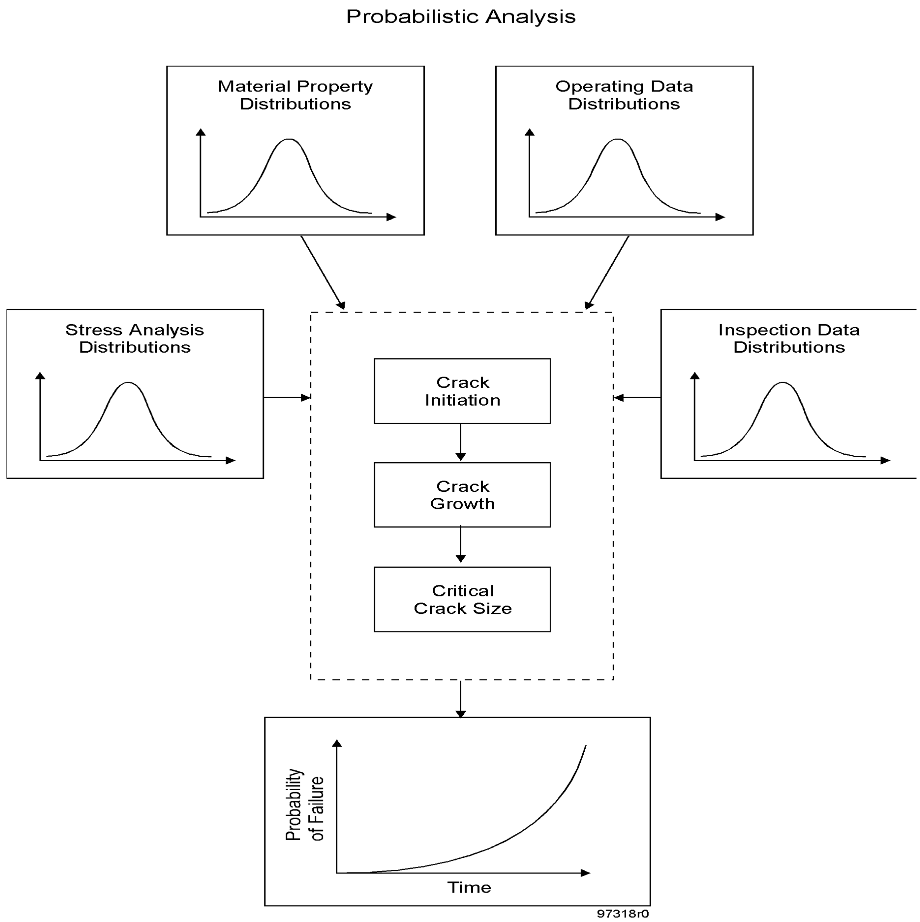

Figure 3-2 Monte-Carlo simulation in LPRimLife

3.3 Commercial Analysis Tools

General purpose finite-element stress analysis programs have been commercially available for over two decades. There are now several programs available for licensing with full technical support and training. Many other algorithms are available for free in the public domain. These tools can be applied to a wide variety of component geometry, material properties, and boundary conditions. Geometry preprocessors or links to computer-aided design (CAD) programs facilitate model generation. Mesh generators have become increasingly automated, producing improved models with less development time. Analysis options include elastic or elastic-plastic static stress, nonlinear gap analysis, modal analysis, and dynamic analysis (steady or transient).

General purpose FEA tools typically lack the specialized preprocessors needed to quickly create geometry and meshes for specific classes of components (for example, steam turbine blades and disk attachments). Turbine blade model development can be time consuming, even for experts, using a general purpose preprocessor and mesh generator. This is due to the complex three-dimensional nature of turbine blade airfoils and attachments. A solution to this is the use of geometry templates as a “front-end” preprocessor for commercial software. These templates are developed specifically for classes of component geometry for which a common mesh generation scheme can apply. Some provide links to import CAD files. The template is essentially a set of commands to the commercial code preprocessor which automates creation of the geometry and mesh, requiring only a minimum of key configuration information to be supplied by the user.

An example of a template designed for analysis of steam turbine blades is the product BladePro developed by Impact Technologies LLC. BladePro works with the ANSYS Parametric Design Language (APDL) to facilitate the complete turbine blade analysis process including geometry generation, mesh generation, boundary condition application, job submission, and post-processing. Specialized post-processing for turbine blade analyses such as Campbell diagram and interference diagram generation is available in BladePro. The BladePro interface program essentially allows non-experts in blade modeling, or ANSYS® in general, to quickly generate and perform an analysis. Additional information on BladePro can be found at:

http://www.impact-tek.com/Engineering/Category.aspx?cat=9

3.4 Comparison of Options

In comparing the options for component stress calculation in support of the EPRI LP turbine corrosion model, the following points are made:

1. accurate evaluation of mechanical stress in areas affected by corrosion requires detailed models capable of calculating both mean and alternating stress amplitudes
2. stress concentration effects in notches and fillets play a role in most observed cases of SCC or CF on actual operating turbines; in general these require special attention in the mesh generation phase to ensure accurate surface stresses
3. accuracy in dynamic response calculations, from which alternating stresses are derived, is dependent on proper estimation of the operating natural frequencies of the blade row

In general it is emphasized that accuracy of the overall corrosion model is equally dependent on both the DFA algorithms described in Chapter 2 and proper stress calculations. Parameters such as threshold stress intensity and critical crack size directly affect predicted component life and these parameters are likewise influenced by stress calculated within the proposed EPRI software.

Table 3-1 below summarizes four options for calculating steam turbine component stress information, and the advantages/disadvantages of each in regards to its potential use the final EPRI corrosion software. The existing EPRI tools BLADE-ST and LPRimLife appear to have some significant barriers for use as either the “foundation” program that the new corrosion tool is implemented, or for use as a separate stand-alone stress analysis module. Several comments in Table 3-1 refer to the issue of maintaining viability of software support in the future. This is a non-technical issue, but nonetheless important to success of the overall effort. Whatever path is selected, the financial support of the future software training, upgrades, enhancements, and maintaining compatibility with current operating systems will come only from the active user community. Commercial FEA tools have large user communities, essentially ensuring ongoing support (however all licensees share in this cost). There has been EPRI software produced in the past that could not sustain a sufficient user community to financially support the product.

Table 3-1 Comparison of options for component stress calculations

options	advantages	disadvantages	comments
BLADE-ST	• existing software • specific preprocessors for blade geometry • Scope: blades, disk rims, disk faces • already has fatigue initiation module	• not commercially available; currently not widely used by industry • not all current blade designs supported • no business case for continuing development • DOS program	High initial cost to convert to current operating systems, no current user base to provide funding for support, limited potential future user base. Lacks templates for many current designs, cost of future template development high.
LPRimLife	• Windows™-based • Already has probabilistic fracture mechanics algorithm • Has algorithm for estimating load redistribution due to crack growth for rim attachments	• Does not perform stress calculations, relied on externally generated model • Stress data file not modular, imbedded in code • Scope: disk rim only, does not include blade root, airfoil, and other features • Weak business case for providing adequate software support	This option would still require a separate FEA calculation be performed. Essentially same as “commercial FEA Program” option except there is a probabilistic analysis framework that could be a basis for a new program
Commercial FEA program	• Can model wide range of component geometries • New blade features can be modeled with general-purpose preprocessors and grid generators. • Ongoing software support viable due to broad multi-industry licensee base (i.e. more than just steam turbine applications)	• Complex model development still requires expertise with preprocessors, and is more time consuming than using specialized code such as BLADE-ST • Requires maintaining a license to commercial FEA tool • No specialized results post-processing	With this option, new EPRI software could be an optional post-processor for a wide range of commercial FEA tools. It would require that stress input data requirements and format be defined, and that users of FEA programs have flexibility to produce these output files
Commercial FEA with turbine blade model generation template	• Leverages commercial FEA tool, which has ongoing support and upgrades due to broad user base • Leverages user base of BladePro, more sustainable than just EPRI members alone • Provides optimal combination of template and general purpose preprocessor and grid generator.	• Additional licensing cost, would require BladePro and ANSYS® licenses • BladePro cannot support other commercial FEA tools	This is the best option from the perspective of ease of turbine blade model generation, both currently and in the future. It would not be constrained that only the licensees of the future corrosion code fund the support and upgrades. Barrier with this option is the need for analysts to maintain licenses for two commercial software products

4 RECOMMENDATION

4.1 Modular Approach

Based on the information presented in Table 3-1, the recommended option is to develop the EPRI advanced corrosion algorithm into a stand-alone probabilistic analysis software module that could be executed following the separate component stress analysis using *any* commercial FEA code. A turbine blade and disk attachment preprocessor template used with the commercial FEA code would facilitate the analysis, but it should not be a requirement for using the corrosion software. A modular analysis tool is expected to have significantly wider use than one that requires use of its own dedicated stress analysis subroutine. An additional advantage is that a library of stress data files for common rotor designs could be established.

The proposed software module would perform the following analyses in an integrated manner:

1. probability versus time of fatigue crack initiation without corrosion effects
2. maximum pit depth due to corrosion, on a probability versus time basis
3. pitting transition to cracking
4. probability of crack depth versus time due to propagation from stress cycles (CF)
5. probability of crack depth versus time due to propagation from mean stress (SCC)

It is recommended that the required stress data be contained in an input file rather than being imbedded in the analysis module. A standard format for the stress input file to the corrosion software will be defined that includes:

1. mean stress distribution associated with rotor speed and steam bending
2. rotor overspeed event frequency and severity
3. harmonic stress at multiples of shaft speed (due to per-rev excitation)
4. modal stress due to aeroelastic (flutter) events

It is recommended that all the evolutionary path data in Figure 2-1 be expressed as statistical distributions to permit a Monte-Carlo simulation.

4.2 Additional Considerations

Local stress distributions in the notch fillets of blade roots and disk steeples have a high gradient near the surface. This situation may also exist at some locations of the airfoil, shroud, tiewire, etc. Characterization of this stress gradient is important to accurate modeling of crack tip stress intensity, and the resulting likelihood that the crack will propagate. In addition, load-sharing among adjacent hooks of the root/attachment could affect whether a crack eventually arrests or continues to propagate. In a design analysis, these considerations may be conservatively overlooked and replaced with simplifying assumptions to reduce complexity of the analysis. However, in a root-cause analysis or damage tolerance analysis (cases where brittle failure has occurred or a crack is detected) it may be necessary to account for the role of changes in the component stress distribution that are caused by a crack of *significant* length. In some cases (particularly for free-standing blades) this includes the possibility that the blade natural frequencies have changed, with a resulting increase in vibration due to mis-tuning. In cases where changes in component stress need to be taken into account, an iterative approach to the combined stress analysis and corrosion model is required.

4.3 Development Plan

EPRI will create a formal functional description for the corrosion software in early 2006, and invite proposals for development. The software will then be in development until third quarter 2007, at which time Beta testing will be conducted. Final release is planned for end of 2007.

5
REFERENCES

1. *Development of Code to Predict Stress Corrosion Cracking and Corrosion Fatigue of Low Pressure Turbine Components*, EPRI 1004190, March 2005.
2. G. Engelhardt, D. D. Macdonald, and B. Dooley "Prediction of the Accumulation of Localized Corrosion Damage to Low Pressure Steam Turbines in Fossil Service", *Seventh Intl. Conf. Cycle Chem. Fossil Plants*, Houston, TX, June 3-5, 2003.
3. *Development of Code to Predict Stress Corrosion Cracking and Corrosion Fatigue of LP Turbine Components: Electrochemical and Corrosion Properties of Turbine Steel,* EPRI, Palo Alto, CA: 2005. 1010184.
4. *Electrostatic Effects in Nucleating Flows of Steam*, EPRI, palo Alto, CA: 2004. 1010738
5. *Turbine Steam Path Damage: Theory and Practice*, EPRI, Palo Alto, CA: 1999. TR-108943 V1 and V2
6. *Proceedings of the Steam and Combustion Turbine Blading Conference and Workshop – 1992,* EPRI, Palo Alto, CA: 1993. TR-102061
7. *Development of an LP Rotor Rim Attachment Cracking Life Assessment Code (LPRimLife),* EPRI, Palo Alto, CA: 1999. TR-110407

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together…Shaping the Future of Electricity

Printed on recycled paper in the United States of America

1010291

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com