RESIDUAL LIFE ASSESSMENT OF STEAM TURBINES

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REMAINING LIFE ASSESSMENT- THE NEED

REMAINING LIFE ASSESSMENT HAS TWO INGREDIENTS:

- INTEGRITY ASSESSMENT, NEEDED BECAUSE:
  - TURBINES OPERATE AT HIGH TEMPERATURES & PRESSURES.
  - THESE OPERATING CONDITIONS, WITH TIME, LEAD TO MATERIAL DEGRADATION & THE FORMATION OF CRACKS/DEFECTS
  - IF NOT DETECTED, CAN CAUSE CATASTROPHIC FAILURES

- ESTIMATION OF REMAINING LIFE BY CALCULATIONS
RLA Studies- Activity Flow

- Cleaning of Components
- Visual Examination
- Magnetic Particle Test
- Dye Penetrant Test
- Metallography & Hardness
- Lab. examination of Replicas
- Ultrasonic Test
- Data Analysis & Lab. Report
- FEM Calculations
- Operational data from site
- Lab. Report
- Final Report
- FEM Calculations
- Operational data from site
- Lab. examination of Replicas
- Metallography & Hardness
- Dye Penetrant Test
- Magnetic Particle Test
- Visual Examination
- Cleaning of Components
Damage Mechanisms

Depending on the working stresses & working environment, turbine components are exposed to various damage mechanisms.

**Mechanism:- Creep**

Slow & continuous deformation of materials due to high temperature exposure even at constant load.

**Causes:**

Dimensional distortion leading to final rupture.

**Affects:**

HP – IP Rotors / Disks / Blades / Fasteners
Steam Chests / Valves
High Temperature Pipeline
Damage Mechanisms

**Mechanism:** Corrosion / Stress Corrosion

The ‘eating away’ of a metal when exposed to a particular environment. The corrosion rate is enhanced when the component is under stress & this type of corrosion is called Stress Corrosion.

**Causes:**

Material loss – may cause failure

**Affects:**

HP-IP-LP blades
Damage Mechanisms

**Mechanism:** Fatigue / Thermal Fatigue

Failure of metal when subjected to repeated or fluctuating stresses much lower than required for failure at single load application. When the stresses are due to thermal cycling it is called Thermal fatigue.

**Causes:**

Failure

**Affects:**

HP – IP – LP Rotors / Disks / Blades / Fasteners
Steam Chests / Valves
Areas Covered

Ideally, each individual component should be 100% examined by Non Destructive & Metallographic techniques during each RLA.

But,

This is not possible because:

• Time constraints.. the work may take months & well exceed overhauling period.

• A more extensive test does not necessarily mean a better test
Areas Covered

Keeping these factors in mind & pooling the knowledge & expertise of designers & testing personnel, BHEL has drawn up a standard testing schedule.

This schedule addresses the various NDT & Metallographic tests to be conducted on each component.

There are different schedules for turbines of different designs & ratings.

In drawing up this schedule it has been ensured that extensive tests, commensurate with the criticality of the component is carried out.

The schedules are being constantly updated based on site experience & feedback.
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<th>VIS</th>
<th>MPI</th>
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An Extract
This normally is in 3 pages
Tests for Integrity Assessment

Integrity Assessment of Steam Turbines is a multi-disciplinary activity, and comprises of:

- Visual Examination
- Dye Penetration Tests
- Magnetic Particle Examination
- Ultrasonic Testing
- In-situ metallography
- Hardness Testing
- Tensile Testing
- Impact Testing
Visual Examination

- **Detects:** Surface breaking defects
- **Applicable to:** All components
- **Need:**
  - a) Macro level damage assessment
  - b) Wide & Shallow cracks cannot be detected by NDT
- **Equipment:** Magnifying Glasses/ Mirrors etc.
Visual Examination

Crack at blade root in diaphragm

Impact damage of blades
Borescopy

- **Detects:** Surface breaking defects e.g. cracks, pits etc.
- **Applicable to:** Turbine Bore, Internal of Chests etc.
- **Pre-Requisites:** Cleaning of surface to remove rust/ scale etc.
- **Need:**
  a) Detect defects in bore / Internal Surfaces which cannot be examined directly
  b) Wide & Shallow cracks cannot be detected by NDT
- **Equipment:** Rigid Segmental Borescope with CCTV
Visual Examination

Borescope

Borescopy

Inclusions in Bore
Dye Penetrant Testing

- **Dectes:** Surface breaking defects
- **Applicable to:** All components
- **Pre-Requisites:** Cleaning of surface to remove rust/ scale etc
- **Sensitivity:** About 3 mm
- **Variants:** Visible or Fluorescent
- **Equipment:**
  - a) Dye Penetration Kit
  - b) Ultraviolet light
Dye Penetrant Testing

Cracks observed in Visual DP & Fluorescent DP (bottom right)
Fluorescent Magnetic Particle Examination

- **Detects:** Surface breaking cracks
- **Applicable to:** All ferromagnetic components
- **Pre-Requisites:** Cleaning of surface to remove rust/scale etc.
- **Sensitivity:** About 2 mm

- **Equipment:** Magnetic Yoke
  Black Light
  Portable Magnetic Units delivering up to 6000 Amps.
  Magnetic Particle Fluid
Magnetic Particle Examination

Magnetic Yoke        Black Light              Portable High Current Source

Cracks detected in MPI
Magnetic Particle Examination

Location of cracks in HP casing detected in MPI
Bore Magnetic Particle Examination

- **Detects:** Surface breaking defects
- **Applicable to:** Bore of turbine rotors
- **Pre-Requisites:** Honing/Grinding of bore to remove rust/scale etc.
- **Equipment:**
  - a) Portable Magnetic Units delivering up to 6000 Amps.
  - b) Borescope
Bore Magnetic Particle Examination

Magnetization of rotor bore
Ultrasonic Testing

- **Dectes:** Volumetric Defects
- **Applicable to:** All components
- **Pre-Requisites:** Cleaning of surface to remove rust/ scale etc.
- **Sensitivity:** About 2 mm
- **Equipment:** Ultrasonic Test Equipment:
  a) USL-32 / USK-7D / USD-15 X
  b) Normal, T-R, Angle probes
Ultrasonic Testing

Ultrasonic Flaw Detectors USD-15X (left) USK 7D (right)

Carrying out UT

Parting plane fastener crack-Detected by UT
In-Situ Metallography

- **Detects:** Micro structural condition, changes, creep damage, micro-cracks

- **Applicable to:** All components

- **Sensitivity:** Microns

- **Equipment:**
  a) Polishing Equipment
  b) Replica Kits
  c) Portable Microscope (Buehler)
  d) Metallograph (Leica)
  e) Image Analyser
  f) Scanning Electron Microscope
In-Situ Metallography

Replicas on a pipe

Metallograph

Portable metallographic microscope

Scanning Electron Microscope
In-Situ Metallography

Crack at weld

Microstructure of rotor

Carbide coagulation at grains

Stress Corrosion Cracking
In-Situ Hardness

- **Dectets:** Hardness degradation due to high temperature exposure
- **Applicable to:** All castings, forgings, welds etc.
- **Accuracy:** ± 5%
- **Equipment:** Hardness Testers (Equotip) with D / G / C bodies

Hardness testing with Equotip-2
Tensile Tests

- **Test:**
  - Tensile Test:
    - 0.2% Proof Stress
    - Ultimate Tensile Strength
    - % Elongation
    - % Reduction in Area

- **Dectects:**
  - Degradation due to high temperature exposure

- **Applicable to:**
  - Fasteners – *This is a destructive test*

- **Accuracy:**
  - ± 1%

- **Equipment:**
  - Universal Testing Machines:
    - 500/250/200/100 KN
    - both conventional & computer controlled
Tensile Tests

250 KN UTM

10 KN UTM

Round tensile specimen & fractured specimens
Impact Testing & FATT

- **Detects:** Degradation due to high temperature exposure
- **Applicable to:** Fasteners – *This is a destructive test*
- **Accuracy:** ± 0.5%
- **Equipment:**
  - a) Impact Testing Machine
  - b) Cryogenic chamber
Impact Testing & FATT

Impact Testing M/C

Charpy impact specimens - before & after fracture

FATT Curve
Testing Techniques- Under Development

Integrity Assessment is a constantly evolving process.

New testing techniques & procedures are being developed which enhance the quality & reliability of the tests.

There are some testing techniques, available with only few select parties in the West, and none in India.

BHEL as the leader in RLA activities in India is on the path of introducing the following state-of-art testing equipment.
In-Situ Chemical Composition

- **Detects:** Chemical Composition
- **Applicable to:** All components
- **Pre-Requisites:** Cleaning of surface to remove rust/scale etc.
- **Sensitivity:** About 2%
- **Equipment:** Portable XRF Metals Analyzer
In-Situ Chemical Composition

Portable Metals Analyser
In-Situ Physical Properties

- **Determines:** Yield Strength, Ultimate Tensile Strength, Hardness, Fracture Toughness
- **Applicable to:** All components
- **Pre-Requisites:** Cleaning of surface to remove rust/scale etc.
- **Sensitivity:** About 10%
- **Equipment:** Portable Automatic Ball Indentation Equipment
In-Situ Physical Properties

PABI Equipment

Comparison of PABI & Conventional results
Boresonic Testing

- **Determines:** Volumetric Flaws
- **Applicable to:** Bored Rotors
- **Pre-Requisites:** Cleaning of surface to remove rust/scale etc.
- **Sensitivity:** About 10%
- **Equipment:** Boresonic Equipment consisting of:
  a) Ultrasonic Flaw Detector
  b) Boresonic Head with probes
  c) Manipulator
  d) Multiplexer
Boresonic Testing
Computational Techniques

The consumed life of a steam turbine component is the sum of the life consumed by Creep & Low Cycle Fatigue

\[
\text{MINER SUM } M_C \text{ IS INDICATOR OF THE LIFE EXPENDED DUE TO CREEP}
\]

\[
\text{MINER SUM } M_F \text{ IS INDICATOR OF THE LIFE EXPENDED DUE TO LOW CYCLE FATIGUE}
\]
FOR STATIONARY COMPONENTS:
\[ M = M_C + M_F = 1 \] WARNING POINT

FOR ROTATING COMPONENTS:
\[ M = M_C + M_F = 0.5 \] WARNING POINT

BOTH ARE DETERMINED USING DESIGN DATA & FROM THE PLANT’S OPERATIONAL HISTORY
Computational Techniques

- Miner sum due to Creep and Low Cycle fatigue are calculated based on the Plant’s operating history and component’s design data.

- As per Miner and Palgren’s rule the Effective Miner sum is the sum of Mc and Mf

- Approaching the Warning Point of Effective Miner Sum indicates that the life of the component has reached its limit.
Computational Techniques

- The difference between the allowable limit of Miner Sum and calculated value of Miner Sum at the time when the R.L.A. study was done indicates the remaining life of the component.

- In addition, the results of Integrity Assessment are also factored in while predicting the remaining life.
Computational Techniques

- The Calculation Group

- Calculates the Steady State & Transient stress distribution using FEM techniques.

- From these results and operational history calculates the life consumed by creep & fatigue.

- Refines the calculations using results of Integrity Assessment.
## A Typical Result

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MINER SUM DUE TO CREEP DAMAGE</th>
<th>MINER SUM DUE TO FATIGUE DAMAGE</th>
<th>TOTAL MINER SUM</th>
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<td>HP Rotor Bore (Inlet Zone)</td>
<td>0.023</td>
<td>0.0201</td>
<td>0.0431</td>
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<tr>
<td>HP Rotor Surface (Inlet Zone)</td>
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<td>0.1867</td>
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<td>IP Rotor Bore (Inlet Zone)</td>
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The Progress

Sites
- Obra
- Korba
- Badarpur
- Singrauli
- Bhusawal
- Wanakbori
- Vindyachal
- Tuticorin
- Satpura
- Nasik
- Koradi
- Bokaro
- Panipat
- Mettur
- Mejia

From 12 MW to 500 MW
The Findings

- Rotor
  - Obra, Satpura

- Disks
  - Badapur, Obra, Neyveli

- Blades
  - Trombay, Ramagundam, Farakka, Birsinghpur
  - Kolagaht, Bokaro, Nyveli, Chandrapur, Vindhyachal, Ropar

- Casing
  - Tuticorin, Badarpur, Ukai, Wanakbori
The Findings

- Chests / Housing
  - Tuticorin, Ropar

- Fastener
  - Singrauli

- Diaphragm / Liners
  - All sites

- Valve / Valve Stems
  - Many sites
Thank You