IMPORTANCE & PROCESS OF RLA STUDIES IN ASSESSMENT OF NEED FOR R&M - A CASE STUDY

CPRI, Bengaluru

What is RLA?

RLA is a technique to examine systematically and monitor the plant, during and after service to assess its future reliability and safety,so as to avoid catastrophic consequences in certain components.

NEED OF REMAINING LIFE ASSESSMENT

ACTUAL LIFE

LIFE EXTENSION

1. USE OF MIN PROPERTIES IN DESIGN
2. FACTOR OF SAFETY
3. CONSERVATIVE OF OPERATION OF UNIT
4. INACCURACIES OF DATA EXTRAPOLATION

DESIGN LIFE

PREMATURE RETIREMENT

1. UNANTICIPATED STRESSES
2. OPERATION OUTSIDE DESIGN LIMITS
3. CORROSIN & ENVIRONMENTAL EFFECTS
4 .METALLURGICAL CHANGES

ACTUAL LIFE

- Health Check-up

- Safety to Continue Operation

- Scientific tool for R & M requirement

          - Run
          - Repair
          - Replace as part of R& M
          - Operational Improvements

CPRI Method of RLA Studies

- **Civil Structures**
- **Mechanical Components**
- Electrical Components
- Instrumentation

Civil Structures

- Visual Inspection
- NDT inspection of Structures
- Concrete Healthiness Inspection
- Water inlet and Outlet Inspection

Mechanical Components

- **Hydro Turbine**

- **Hydro Generators**

- **Other components such as**

  - Stator casing, brackets etc. for cracks and tightness.

  - Bearings for wear and tear.

  - Commutators, brushes, brush holders and slip rings for wear and tear and other damages.

  - Coolers for deposits, corrosion of tubes and water chambers.

  - Fan blade surfaces, bearing and contact area.

Life Evaluation by Inspection

FAILURE	DAMAG CAUSE	PHENOMENON	LIFE EVALUATION	INSPECTION METHODS
• FATIGUE	• Cyclic stresses	• Growth of crack	• Stress analysis • Surface crack inspection (PT,MT)	• NDT inspection • FEM Analysis
• CORROSION • EROSION	• Corrosion due water • Erosion due to water	• Thickness thinning	• Annual thickness measurement	• Theoretical Calculations

Electrical Components

- There is no Model or criteria for estimation/prediction of remaining life of any HV Equipment in service. RLA in true sense consists of the following steps:

- Collection of O&M History of the equipment.

- Visual Examination of the equipment.

- Conducting appropriate diagnostic tests to assess the present status of the equipment.

- Analysis of the data to detect the extent of deterioration or to detect the defective component.

- Recommendation of appropriate remedial measures to avoid
  - Forced outages.
  - Extend the residual life
- The diagnostic tests need to be conducted periodically [every (2 / 3 / 4 years)] to monitor the trend in the parameters.
- Data logged over the years and trend analysis provide useful information to initiate appropriate remedial measures to extend the life of the equipment.

- CPRI conducts RLA Studies on the HV equipment as per the procedure described above.

- No quantitative assessment of life in terms of years is possible with the data generated.

- However, on the basis of the analysis of the data, appropriate remedial measures such as run, repair or replacement to extend the remaining life of the equipment shall be recommended.

Diagnostic Tests on Power Transformers

- Tests on transformer
  - IR/PI
  - Tan delta & Capacitance
  - Dielectric Spectroscopy or Recovery Voltage Measurement
  - Winding Resistance
  - Turns Ration Measurement
  - Short Circuit impedance Measurement
  - Magnetising Current Measurement
  - Sweep frequency Response Analysis (SFRA)

Diagnostic Tests on Power Transformers

- Tests on transformer Oil
  - Tests on Transformer oil sample as per IS1866-2000
  - Dis -sovled Gas Analysis
  - Furan Analysis
- Tests on Paper Sample
  - Degree of Polymerization Test

Diagnostic Tests on Generators

- Tests on generator Stator
  - IR/PI
  - Tan delta and capacitance
  - Partial Discharge Test
  - DC Leakage Current Test
  - Surge Comparison Test
  - Winding Resistance Test
  - ELCID Test
  - Wedge Mapping Test
- Tests on generator Rotor
  - IR/PI, RSO Test
  - Pole drop test, Rotor Impedance, Rotor Resistance

Diagnostic Tests on Switchyard Equipment

- Tests on Circuit Breakers
  - Dynamic Contact Resistance
  - Static Contact Resistance
  - No Load Operating Timings
  - Simultaneous Opening of Poles
  - Contact Bounce during Operation
  - Operating Coil Resistance
  - Operating Coil Insulation resistance
- Tests on Instrument Transformers
  - IR/PI
  - Tan delta and Capacitance

Diagnostic Tests on Switchyard Equipment

- Tests on Lightning Arresters
  - Third Harmonics Resistive Leakage Current Measurement
- Tests on Power Cables
  - IR/PI
  - VLF Tan delta & Capacitance
  - Partial Discharge Measurement

CASE STUDIES

1. RLA Study on 6.6kV 5.888MVA Hydro Generator Unit # 02 of Gumti Hydro Electric project (Stator)

Phase	Insulation Resistance (GΩ)	Polarization Index	DC Leakage current at 5kV (μ A)
R	0.414	1.57	12.80
Y	0.406	1.58	13.40
B	0.369	1.51	14.40

Phase	Tan delta (%) @1.32 kV	ΔT (%)	ΔC (%)
R	19.098	0.2665	0.8531
Y	19.246	0.2905	1.0128
B	19.190	0.2575	0.8920

ELCID test has been carried out on the stator core of the Generator to detect imperfections / faults and hot spots in the stator core. Fault currents were more than the maximum permissible limit of 100mA.

CASE STUDIES

1. RLA Study on 6.6kV 5.888MVA Hydro Generator Unit # 02 of Gumti Hydro Electric project

RECOMMENDATIONS:

The diagnostic test data indicate substantial ageing of the stator winding structure. The stator winding insulation system exhibits abnormally high dielectric losses. The core laminar insulation exhibits high fault currents. From the analysis it can be inferred that the stator winding structure is not healthy. As the machine is already 40 years old and in view of long term reliability and availability of the machine, it is recommended for replacement of the entire stator winding structure and core with new class F insulation. Application of class F insulation not only enhances reliability but also enables uprating of the generator output power to the extent of about 25%.

CASE STUDIES

1. RLA Study on 6.6kV 5.888MVA Hydro Generator Unit # 02 of Gumti Hydro Electric project (Rotor)

Sl. No.	Test Parameters	Measured Value
1	Insulation Resistance (MΩ)	0.01
2	PI	1
3	Conductor Resistance (mΩ) @ 25°C	72.615
4	RSO Test	Unstable pattern, inter-turn fault observed
5	Field impedance (Average value) (Ω)	15.7736

RECOMMENDATIONS:

Insulation condition of the rotor winding is not healthy. The rotor winding structure is highly contaminated and deteriorated. Inter turn insulation of the poles also exhibits symptoms of deterioration. As the machine is already 40 years old and in view of long term reliability and availability of the machine, it is recommended for replacement of the rotor winding poles along with the stator winding structure and core with new class F insulation system.

CASE STUDIES

2. RLA Study on 5.888MVA, 6.6/66kV Generator Transformer # 02

Insulation section	Insulation Resistance 60sec (GΩ)	Polarization Index	Tan δ (%)	Moisture content (%)
HV winding versus LV winding connected to Grounded tank	0.0724	0.98	11.016	5.11
HV winding versus LV winding (Ungrounded)	0.0907	0.99	11.474	5.40
LV winding versus HV winding connected to Grounded tank	0.0367	1.00	9.786	5.65

The oil test results are normal and the oil parameters are within permissible limits as per IS 1866:2000. The DGA results exhibits high concentration of ethylene gas indicating possible over heating or thermal fault in the transformer. Furan analysis shows presence of high quantity (4830 ppb) of furanic compounds.

CASE STUDIES

2. RLA Study on 5.888MVA, 6.6/66kV Generator Transformer # 02

Recommendations:

The diagnostic test data indicate abnormally high dielectric losses and high moisture content in the transformer insulation system. The oil data also indicates probable thermal fault and high concentration of furanic compounds.

The transformer is not healthy. Considering age of the transformer and its present poor status, and in view of long term reliability and availability, it is recommended to replace the transformer with a new one.

CASE STUDIES
72.5 kV, 1600 A, SF$_6$ Circuit Breaker No.3 of Feeder-5

- The test for operating time indicates multiple bounces observed in Y phase.

- The static contact resistance values are normal in R & B phases but are slightly on the higher side in Y-Phase.

- Dynamic Contact Resistance (DCR) curves indicate possible pitting & erosion / surface contamination of contact tips in the Y and B Phases.

- The test on operating coil indicates no major abnormality. Variation of operating coil resistance shall be within $\pm$ 10% of the commissioning test values. Insulation resistance test on coil indicates no abnormality.

- The pedestal of the mechanism enclosure is damaged. The observed gas pressure is lower. Gas charging may be done at the next available opportunity.

CASE STUDIES

Recommendation:

The circuit breaker is not healthy. In view of long term reliability and availability, it is recommended for replacement of the circuit breaker by a new one.

CASE STUDIES

4. RLA Study on 11kV, 1x500sq mm XLPE cable

Phase	IR (GΩ)	Tan delta (%)	Capacitance (nF)
R	36.80	0.031	71.07
Y	0.620	0.509	74.06
B	111.0	0.026	71.20

RECOMMENDATIONS:
The power cables are not healthy. It is recommended to replace the cables along with the GT for high long term reliability and availability.

CASE STUDIES

5. RLA Study on Instrument Transformers

CTs Identification Details		Phase	IR 60 sec (G W)	Tand (%) @ 10 KV	Assessment & Recommendation
Feeder #1	Sl. No. 6128822	R	0.384	0.951	Generally healthy
	Sl. No. 2205679	Y	0.648	0.674	Generally healthy
	Sl. No. ---	B	7.40	2.426	Not healthy recommended for replacement
Bus CT	Sl. No. ---	R	0.00502	---	Generally healthy
	Sl. No. ---	Y	1.73	7.112	Not healthy recommended for replacement
	Sl. No. ---	B	0.0733	30.600	Not healthy recommended for replacement

PTs/CVTs Identification		Phase	IR 60 sec (G W)	Tand (%) @ 500V	Recommendations
Feeder #1 PT	Sl. No. 6126397	R	3.050	3.858	Not healthy recommended for replacement
	Sl. No. 6126391	Y	0.198	14.834	Not healthy recommended for replacement
	Sl. No. 6126386	B	2.760	3.408	Replacement
Feeder #2 CVT	Sl. No. IB 041099	B	---	0.519 (@10 kV)	Normal

CONCLUSIONS

- Procedure/Process of RLA has been discussed.

- No quantitative assessment of life in terms of years is possible with the data generated.

- However it helps in assessing the present state and condition of the plant equipment which in turn enables the asset managers to identify the R&M needs.

- It also enables to forecast the budget in the DPR for R&M needs.

- RLA studies are vital tools for preparation of DPR for RMU&LE old Hydroprojects.

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

General layout of penstocks

Severe dent on Penstock No. 1

Flange leakage in Penstock No.4

Severe corrosion on rivets

Porosity in Saddle support

Penstocks under process of painting

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

OBSERVATIONS :

One deep dent around 50 mm depth and two minor dents around 15 mm depth were observed on the pipeline no. 1 between the first & second anchor block at the location near to the Saddle Support No.2

The thickness measurements of Penstock shells at the top of the penstocks on all pipe lines were almost matching with that of the design values whereas near turbine i.e downstream the thickness were found to be less compared to the design values

Minor porosity was observed in very few locations on the masonry saddle supports & looseness in some anchor blocks which represented the weakness of foundation

Dye penetrant inspection, magnetic particle test & ultrasonic inspection were carried out on the welded joints of the penstocks and these inspections did not reveal any abnormalities.

The quality of painting of penstocks appeared to be good. The red oxide primer with epoxy (Black) paint was given to the penstocks as per the normal practice

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

RECOMMENDATIONS :

From the observations and analysis, it is found that penstock pipelines appear to be in good condition and there is no need for immediate attention to be paid towards the repair work.

The analysis revealed that the factor of safety is about 2.45 and it meets the BIS requirement of 1.5 to 3. The pipelines will have to be strengthened for continued operation of the system especially in the downstream pipes. Before taking up any further action in this direction during Renovation & Modernization programme, it is necessary to carry out detailed analysis like survey for the L-section of penstocks, physical properties evaluation of the shell material, etc.

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

RECOMMENDATIONS (contd..) :

However, it was recommended for the following few maintenance aspects which are to be attended immediately:

Valve house needs power connection and communication from power house.
The valve house is presently unmanned, needs to be manned with direct communication from power house.
The dents on the pipeline no. 1 between the first & second anchor block at the location near to the Saddle Support No.2 & 3 are to be repaired.
Leakages in the expansion joints of all penstocks are to be prevented / arrested.
The routine maintenance of all the manholes of the penstock pipelines have to be carried out & documented.
Few foundations of saddle supports & anchor blocks are found to be weak, which needs to be strengthened.
Expansion joints are welded on the downstream of Anchor Block – 8, which is not a good practice and need continuous / regular monitoring of the joints for any abnormalities.

It is also recommended that the practices of regular visual inspection of penstocks, clearing of vegetation, painting whenever needed, etc. are to be continued. Some of the riveted joints found to be in moderate rusted condition and the practice of coating should be continued periodically.

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

RECTIFICATION AND STRENGTHENING OF PENSTOCKS :

The following procedure was adopted for rectification and strengthening of penstocks:

- Cutting and removing of existing pipe in between the riveted joints.
- After removal of the riveted joints, the remaining pipe fitted into the position with the upper pipe. These pipes are joined by welding process after proper edge preparation like beveling and grinding.
- The gaps formed due to shifting of penstocks upward in the penstock are fixed with new pipes with equivalent material grade or higher grade material.
- Proper care has been taken to fix in position with existing substructure / concrete anchors / supports.
- 100% radiographic inspection of welds and ultrasonic tests are carried out to check the quality of welds[9].
- Steel stiffeners are provided to the existing penstock in the downstream line at an interval of 2m to strengthen the old penstock.
- Painting of penstock internal and external surfaces with priming coat of zinc rich primer followed by two coats of Epoxy paint. Before paining process, thorough scarping and cleaning of surfaces with sand blasting has been carried out.

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

RECTIFICATION AND STRENGTHENING OF PENSTOCKS (Contd…) :

The following procedure was adopted for rectification and strengthening of penstocks:

- All the bolts and gland packing of expansion joints are replaced with new bolts, nuts, washers and gland packing.
- Gaskets, bolts and nuts, etc. of manholes are replaced with new ones including cleaning, greasing, etc.
- Hydraulic testing of penstock from main inlet valve to butterfly valve has been carried out.

Residual Life Assessment of 8 MW Hydro Power Plant Penstock Pipelines

CONCLUSIONS :

Residual life assessment of all 4 penstock pipelines was carried out successfully using various non-destructive test methods such as visual inspection, dimensional measurement, dye penetrant inspection, magnetic particle inspection, ultrasonic flaw detection, in-situ hardness measurement. Design validation and suitability of penstocks was carried out using software and factor of safety has been calculated for the existing penstocks. Recommendations have been given for immediate action to be taken for some components.

For extension of life and to meet the demands of Renovation, modernization and uprating capacity, rectification and strengthening of penstocks were carried out. All the riveted joints in the penstock are cut, removed and joined by welding process. New pipes with same material grade and of 22mm thick were inserted in the gaps and welded. Hydraulic test was carried out after completion of all rectification and inspection work to check for any leakages or weak points in the penstock.

The unit has successfully generated uprated capacity of 9 MW with the rectified and strengthened old penstock pipeline. The unit is running continuously without any operational & maintenance problems.

Health Assessment of 126 MW Hydro Generator Shaft - Case study

❑ **R & M of Hydro Units**

- Major components Generator & Turbine
  - ➢ Insulation
  - ➢ Rotor poles
  - ➢ Turbine runner

- Generator and Turbine rotor shaft
 - ➢ Retained (Factor of safety –margin)

- **CRITICAL ISSUE**

  - Most of the older units : > 50 years old
  - Heavy sectioned   and long length (12 meter long x 900 mm diameter)
  - Long lead time required (two years)

  - No proven Ultrasonic available
  - All the shaft - with inherent cracks   were used

IN SERVICE CONDITIONS

  - Cracks grow in service
  - Growth rate is a function of material properties (Yield strength) and
  - Uprating through R & M increases the operating stress levels and increase the growth rate
  - Reach the critical stage without warning - excess vibrations
 - Abrupt failure

Conventional Ultrasonic test

- Do not give the crack orientation
- Cracks adjacent to each other and orientation not possible

Probe

RF   RB

Time (depth)
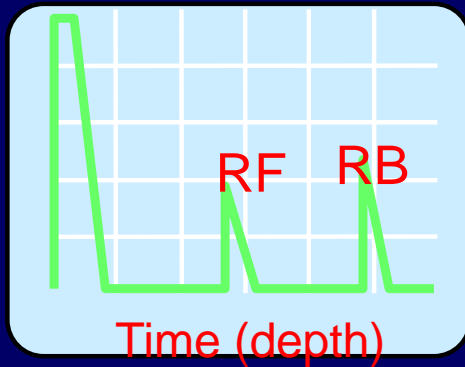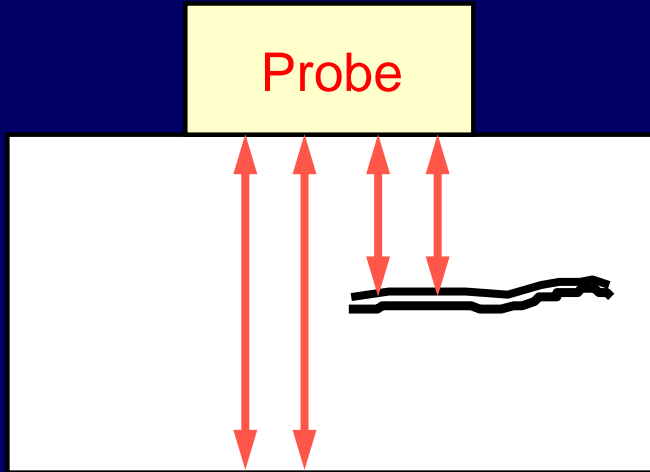
Application of Phased Array Technology based Inspection for Rotor shafts

- Multi crystal probe and Electronically tuned
- Crack orientations possible
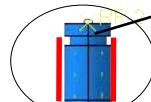- Volume based inspection rather than point inspection
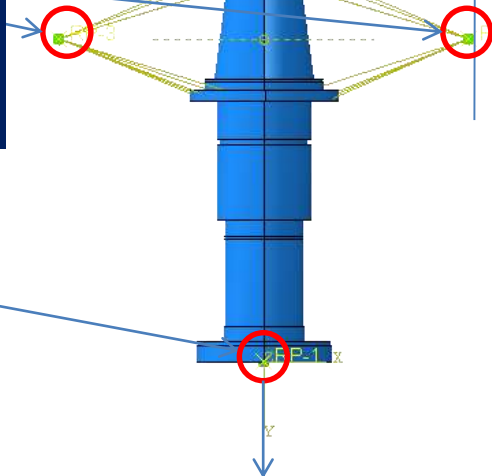

Crack indications
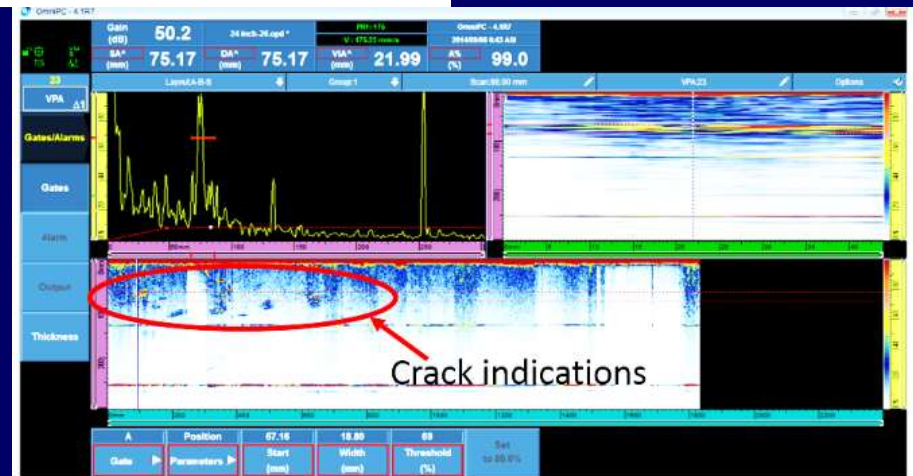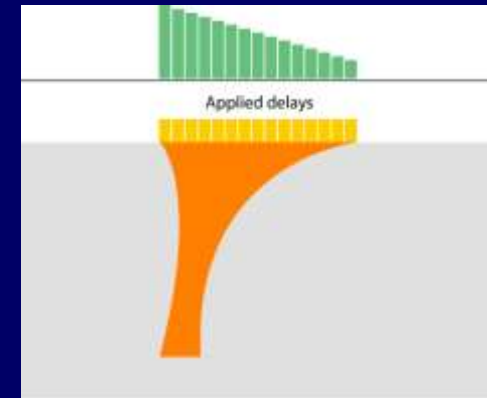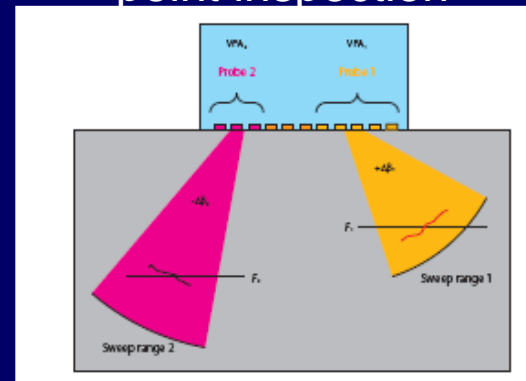
Health Assessment of 126 MW Hydro Generator Shaft - Case study

Self weight of the shaft - - 42 tons

3330 mm

Rotor poles and other masses 3,33,500 kg

Rotor shaft mass 80,600 Kg
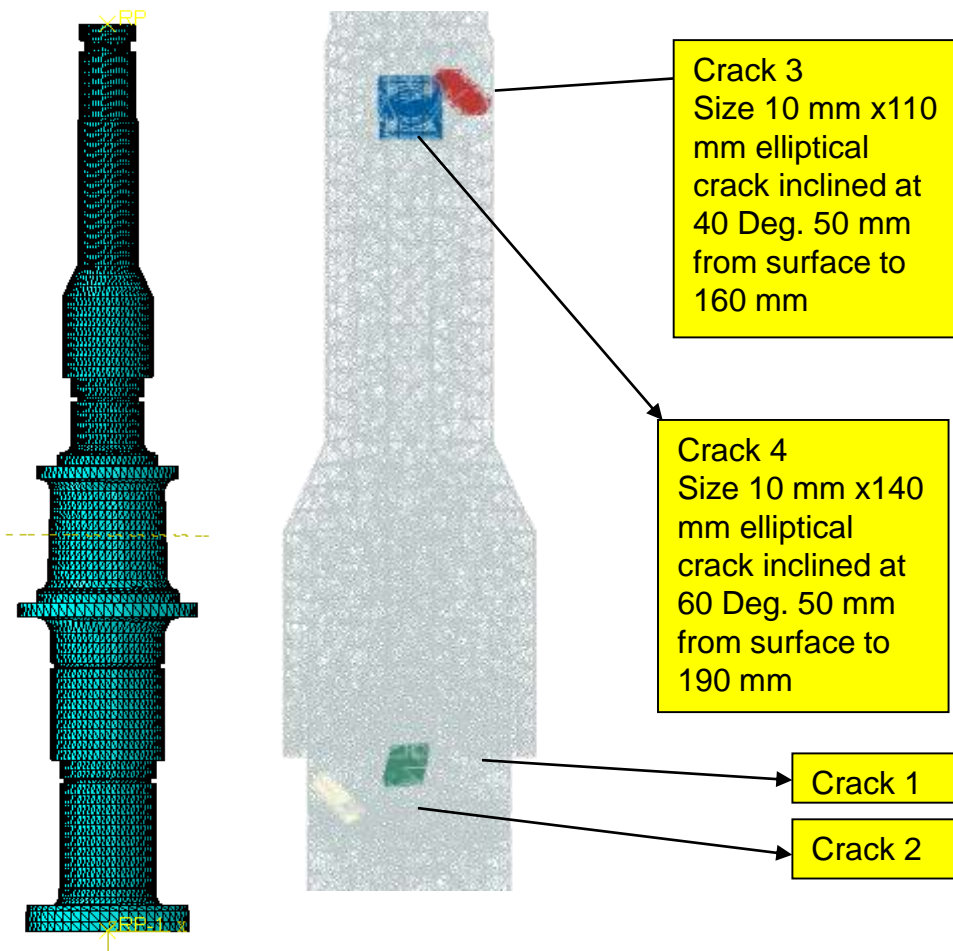
a) Site Inspection
   - NDT tests
      - Advanced UT – (PAUT)
      - Magnetic particle inspection
      - Liquid Penetrant inspection
b) Lab. Damage Tolerance studies
   - Life assessment of cracked rotor
      - Fatigue and crack growth rate
      - Remaining Life estimation

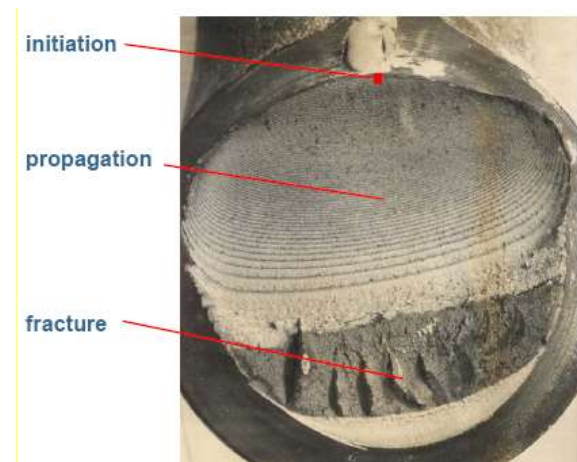# Evaluation of Crack Growth rate during service – FEM based modeling

Crack 3
Size 10 mm x110 mm elliptical crack inclined at 40 Deg. 50 mm from surface to 160 mm

Crack 4
Size 10 mm x140 mm elliptical crack inclined at 60 Deg. 50 mm from surface to 190 mm

Crack 1

Crack 2

Meshed Geometrical model of Gen.rotor shaft (79500 Tetra elements)
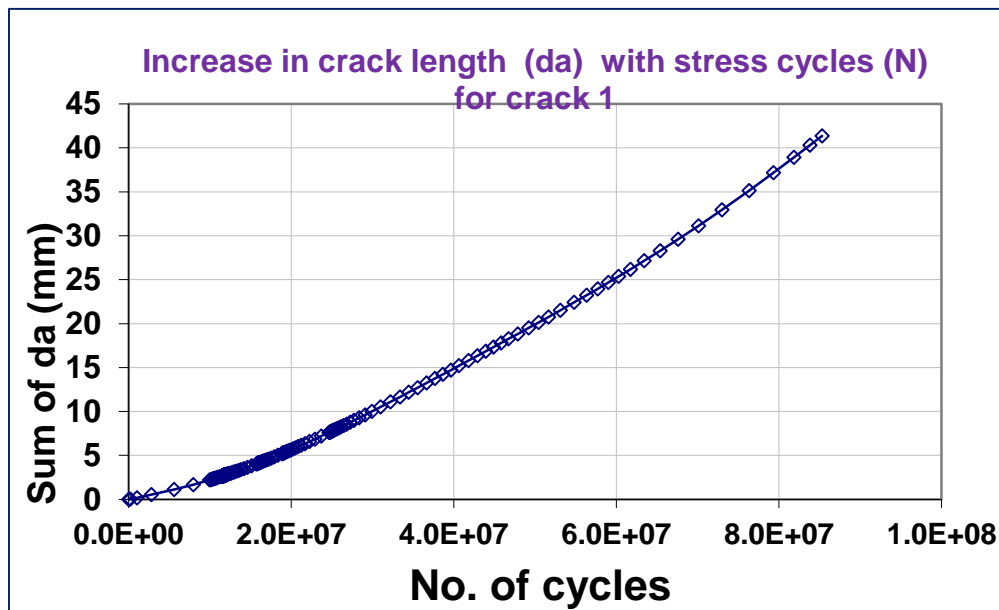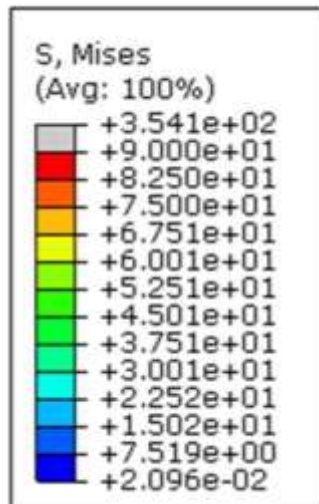

initiation
propagation
fracture

Stages in Fatigue Life

Analysis carried out:

- Stress analysis of shaft
  - Identification of critical stressed region
- Fatigue life of un-cracked shaft
- Crack growth rate of unstable crack in cracked rotor
- Remaining life based on conditions of crack reaching the surface

Crack Growth rate of Generator Shaft

S, Mises
(Avg: 100%)
+3.541e+02
+9.000e+01
+8.250e+01
+7.500e+01
+6.751e+01
+6.001e+01
+5.251e+01
+4.501e+01
+3.751e+01
+3.001e+01
+2.252e+01
+1.502e+01
+7.519e+00
+2.096e-02

Increase in crack length (da) with stress cycles (N) for crack 1

Sum of da (mm) vs No. of cycles

Fatigue Life of Un-cracked shaft = 3.20 x10E9

Sl No	Crack size	No of cycles	Equivalent no. of Days
1	20.1	5,04,28,232	210
2	29.6	6,76,01,489	281
3	42.4	8,53,07,505	355
4	50	~8,80,00,000	366

" Suggested for re-inspection of the shaft close to 250 days of operation"

Health Assessment of 126 MW Hydro Generator Shaft - Case study

CONCLUSIONS :

The PAUT technique has identified all the crack like defects present in the rotor shaft. Most of the cracks were observed to be close to the ID side of shaft and their orientation is observed to be slightly angular with respect to the shaft axis (less than 20°)

The minimum depth to which the defect (crack tip) observed is close to 70 mm from the OD of the shaft. Thus any crack needs to grow 70 mm to reach the surface, which is considered the end of life.

The stress analysis of the shaft, the area averaged maximum shear stress was observed to be approx. 39.3 MPa in 966 mm diameter regions close to Generator-Turbine bolting flange. The allowable design vale of shear stress provided by OEM is 54.9 Mpa.

The fatigue life of the generator shaft without any defect for the rated design capacity is 1012 cycles which is equivalent to life in excess of 75 years.

The critical crack growth rate in cases of selected large size cracks studied was estimated to be 0.983 mm per year. The actual no. of service hours of the unit is approx. 233180 hours equaling to 2.33 x109 cycles. Keeping in view the critical crack location as 70 mm from OD, the crack is expected to reach the surface in not less than 10 years at the estimated growth Rates.

Thank you for your kind attention