B1 to B4 Rehab

Assessment of Reused Components

Commission Presentation

August 7, 2017

Purpose

Review finite element analysis and current condition of components proposed for reuse.

Review recommendation to exercise existing contract options to replace some components.

Board Action for Budget Revision and FWO's to purchase new items, to meet contract schedule requirements.

Background

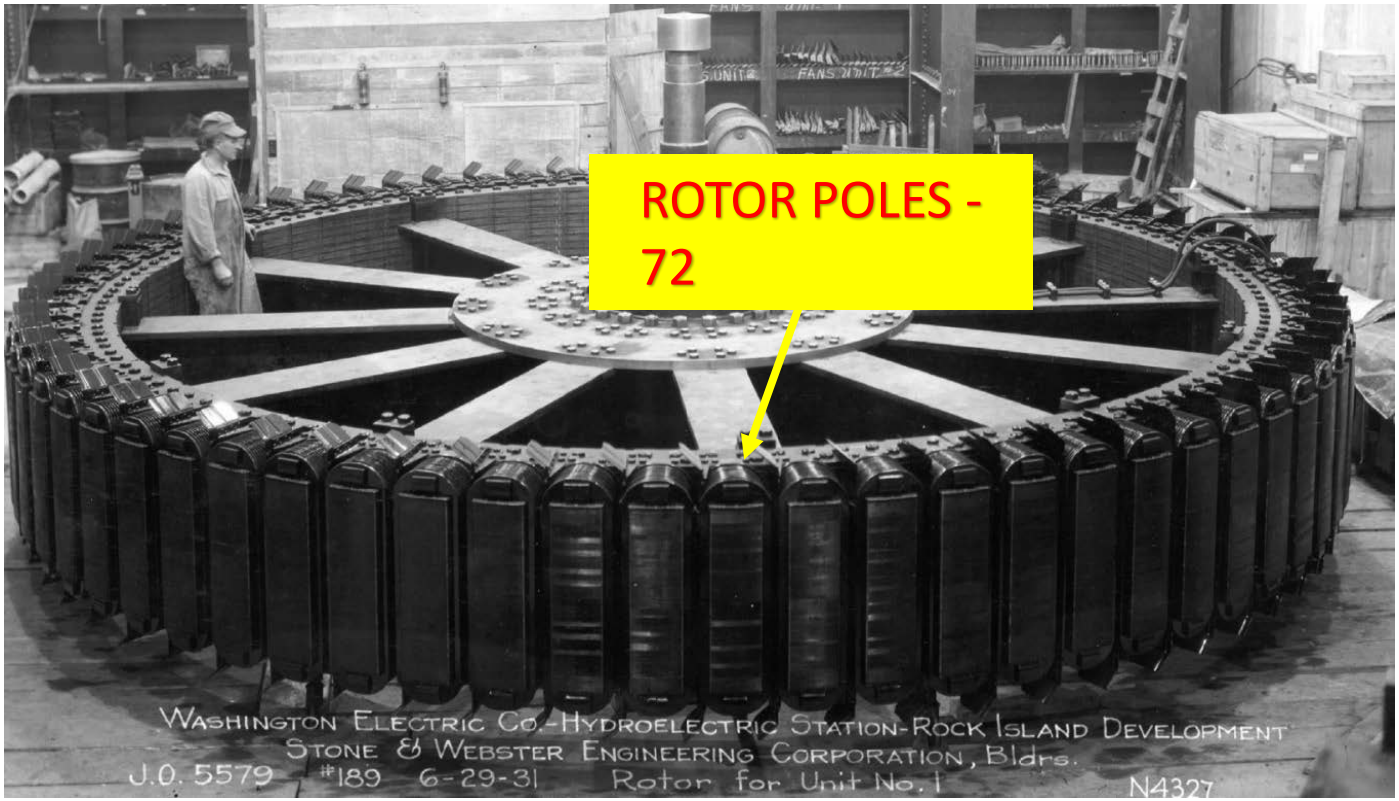
Contract proposes to refurbish components if finite element analysis (FEA) and condition assessment show the component can operate for the 50-year design life. Items include:

- Rotor Field Poles
- Upper Bracket
- Generator Brake system
- Generator shaft, thrust collar, high hat, thrust runner
- Generator Guide Bearing
- Thrust bearing
- Lower bracket
- Turbine guide bearing housing
- Gate Ring, gate arms, link pins, thrust caps
- Wicket gates

FEA Results to Date

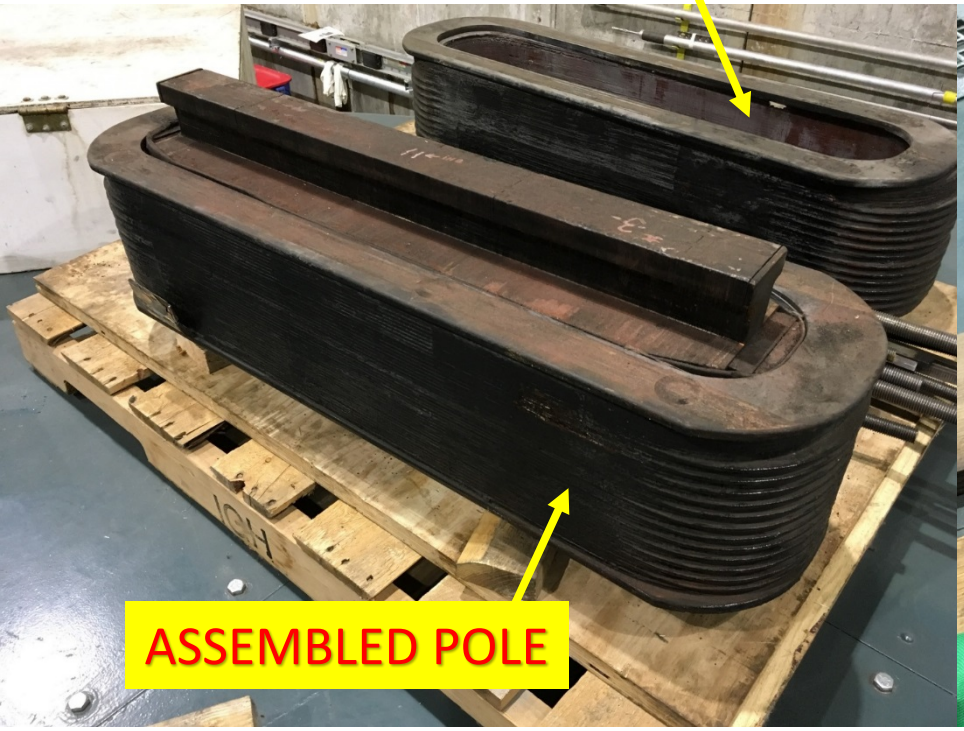
- FEA of reused components 85% complete.
- Items with less than 50-year remaining fatigue life and stresses greater than allowables for at least 1 load case include:
  - Rotor pole L bracket for unit runaway case.
  - Generator shaft keyway connections at maximum output.
  - Wicket gate body and stems at maximum head.

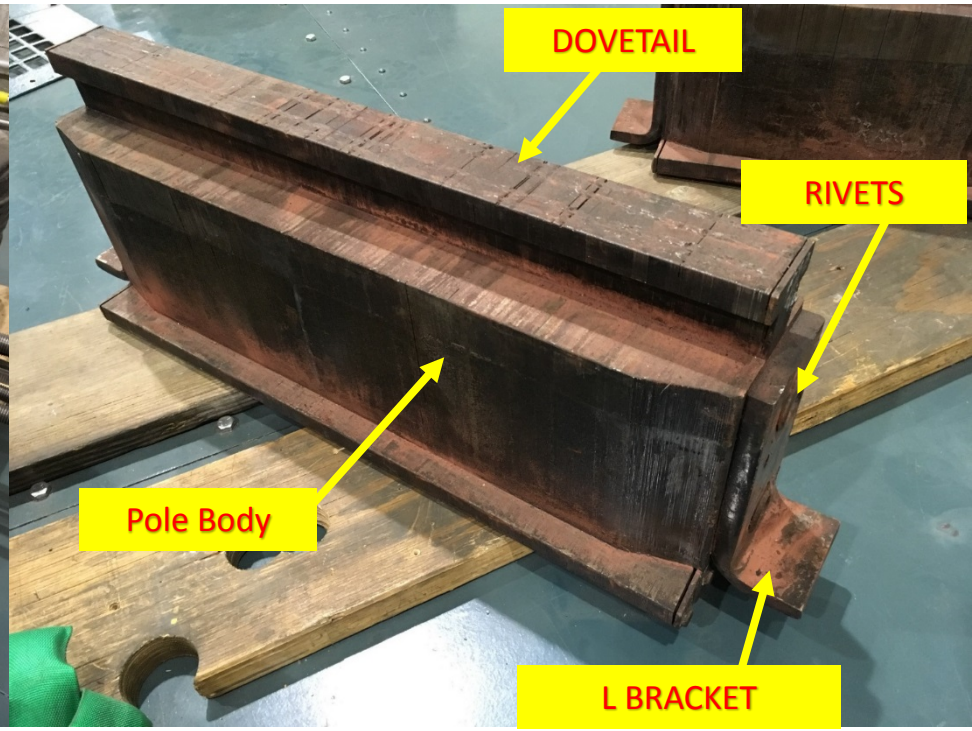
  - Gate ring FEA not yet completed.



B1 ROTOR FROM 1931, ROTOR POLES TODAY ARE STILL ORIGINAL

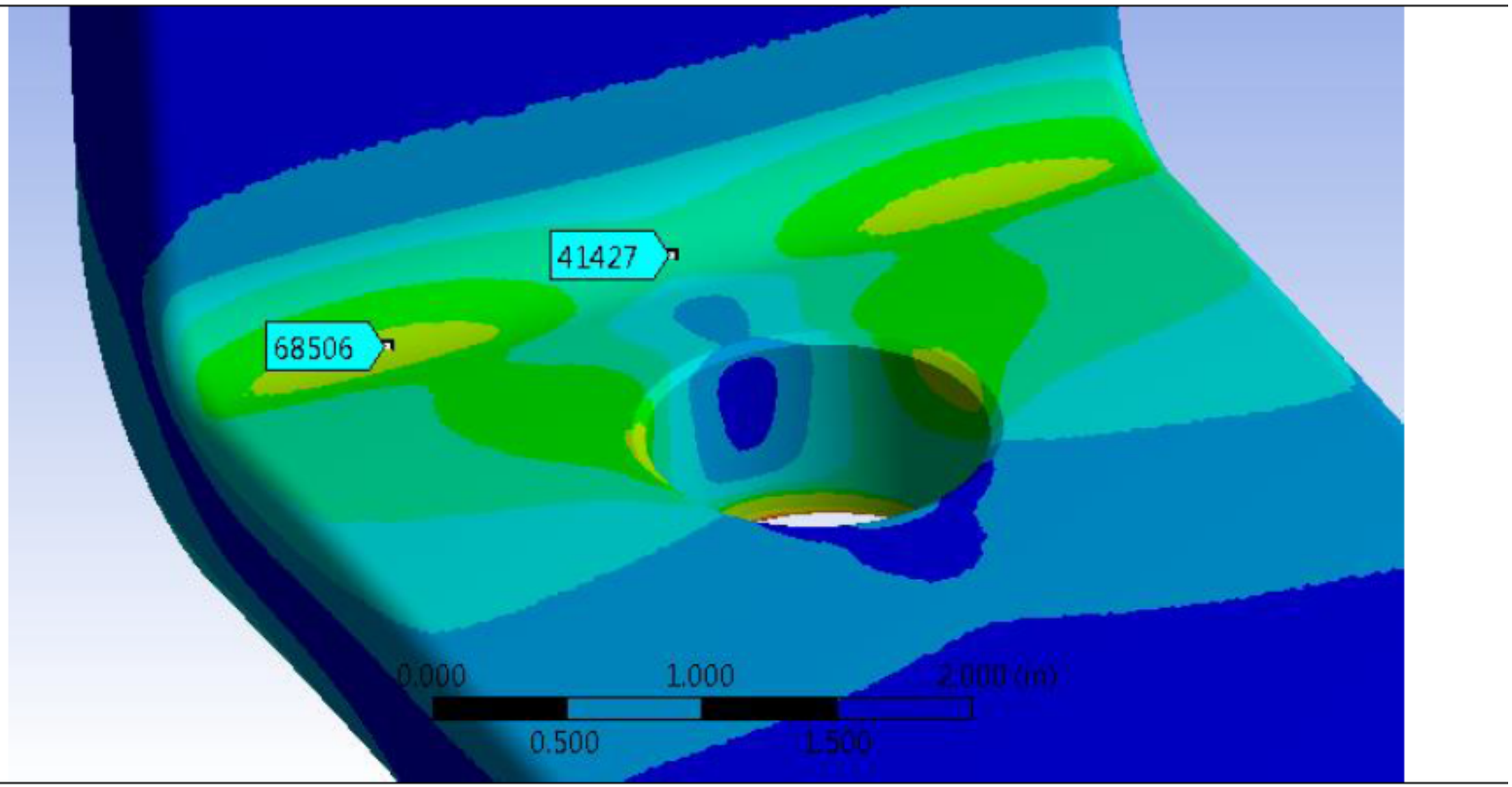
B1-B4 Rotor Pole





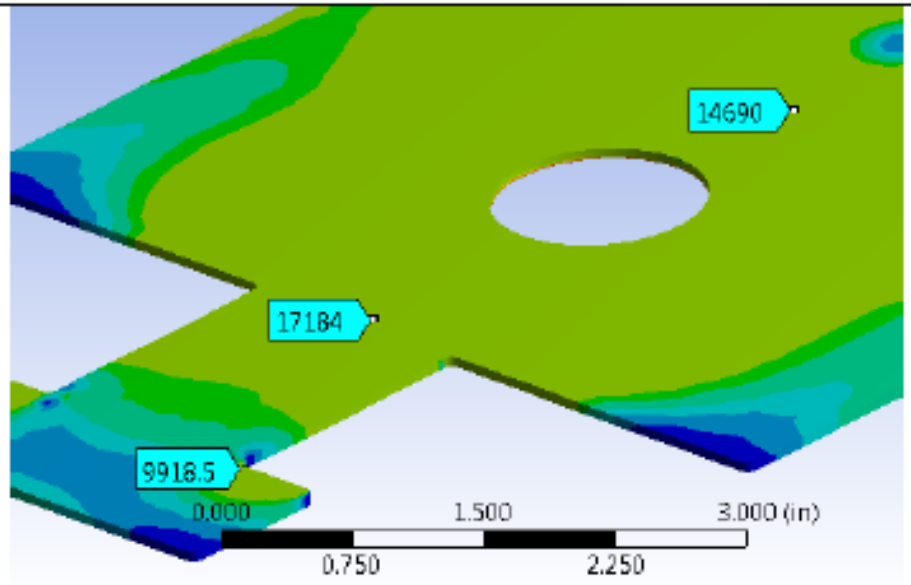
Pole L Bracket FEA

3.3.8 Results - static stresses



Von Mises stress in top side of endplate radius at runaway.
Bulk: $P_L + P_b \epsilon$ (41.4ksi,...68.5ksi) > > 1.155 x 0.667 x Sy = 31.6 .: not acceptable per contract
This region is under serious risk of plastic collapse during runaway speed.
Local: $P_L + P_b + Q + F = 68.5ksi \rightarrow$ fatigue analysis conducted for completeness

Pole Body Lamination FEA

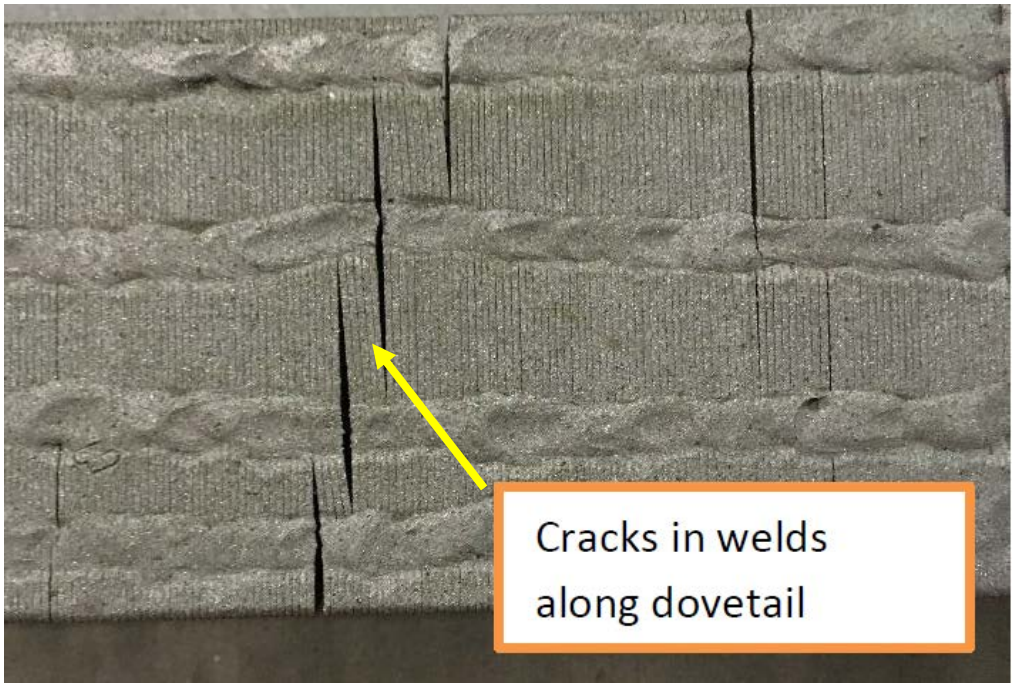


Von Mises stress at dovetail radius and dovetail neck at runaway speed.
Local: $P_L + P_b + Q + F = 9.9$ksi → fatigue analysis required
Bulk: $P_L + P_b = 17.1 < 1.155 \times 0.667 \times Sy = 27$ksi .: acceptable per contract

Pole Condition Results to Date

- Condition assessment performed for rotor poles. 6 poles removed for evaluation.
- Problems (similar in all 6 of 72 inspected)
  - Rivets: some cracked and loose
  - Dovetail: cracks in welds
  - 90% probability pole body will not last 50 years
  - Winding: copper looks to be reusable if reinsulated.

Pole Body Defects



B4 copper winding after insulation removal

Pole Recommendation

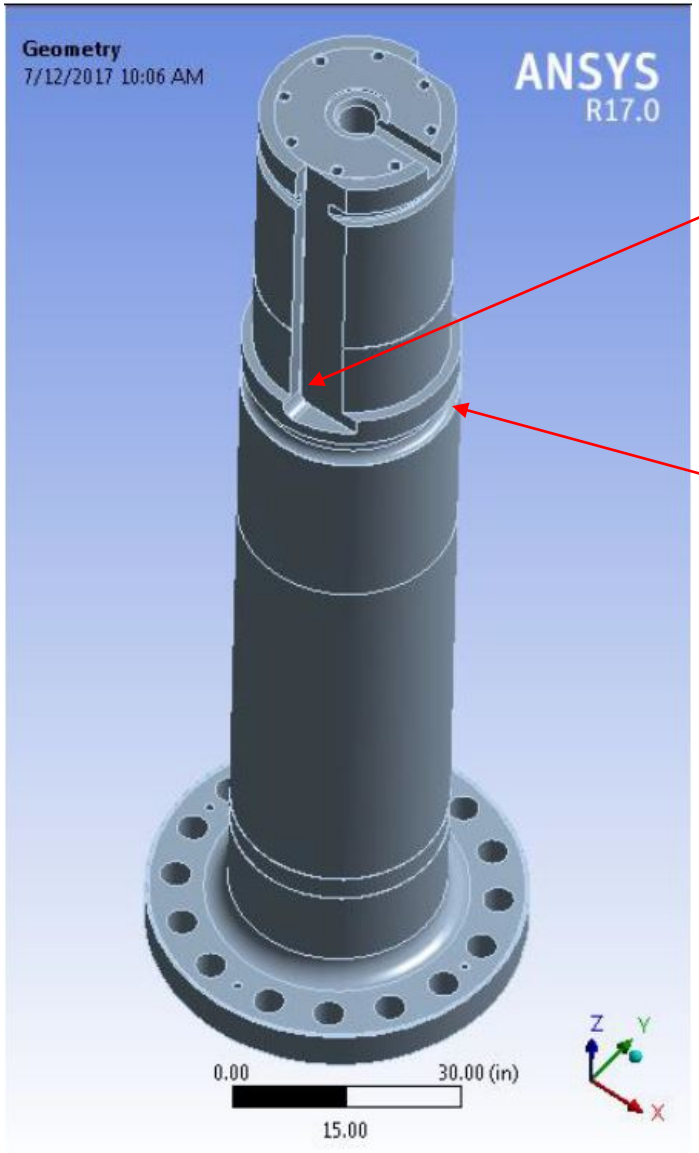
Current scope is to refurbish (disassemble, inspect and reinsulate winding) for $500k ea.

- Contract has option for new poles at $1.15 million per unit additional cost ($1.65M).

➢ Recommendation – Because of cracks in material and overstress at runaway, propose to replace pole body and reinsulate winding all 4 units.

- Cost estimated at $750k per unit additional cost ($1.25M).

Generator (Gen) Shaft FEA



Rotor spider to shaft keyway

Axial thrust bearing keyway

Gen shaft FEA at rotor keyway

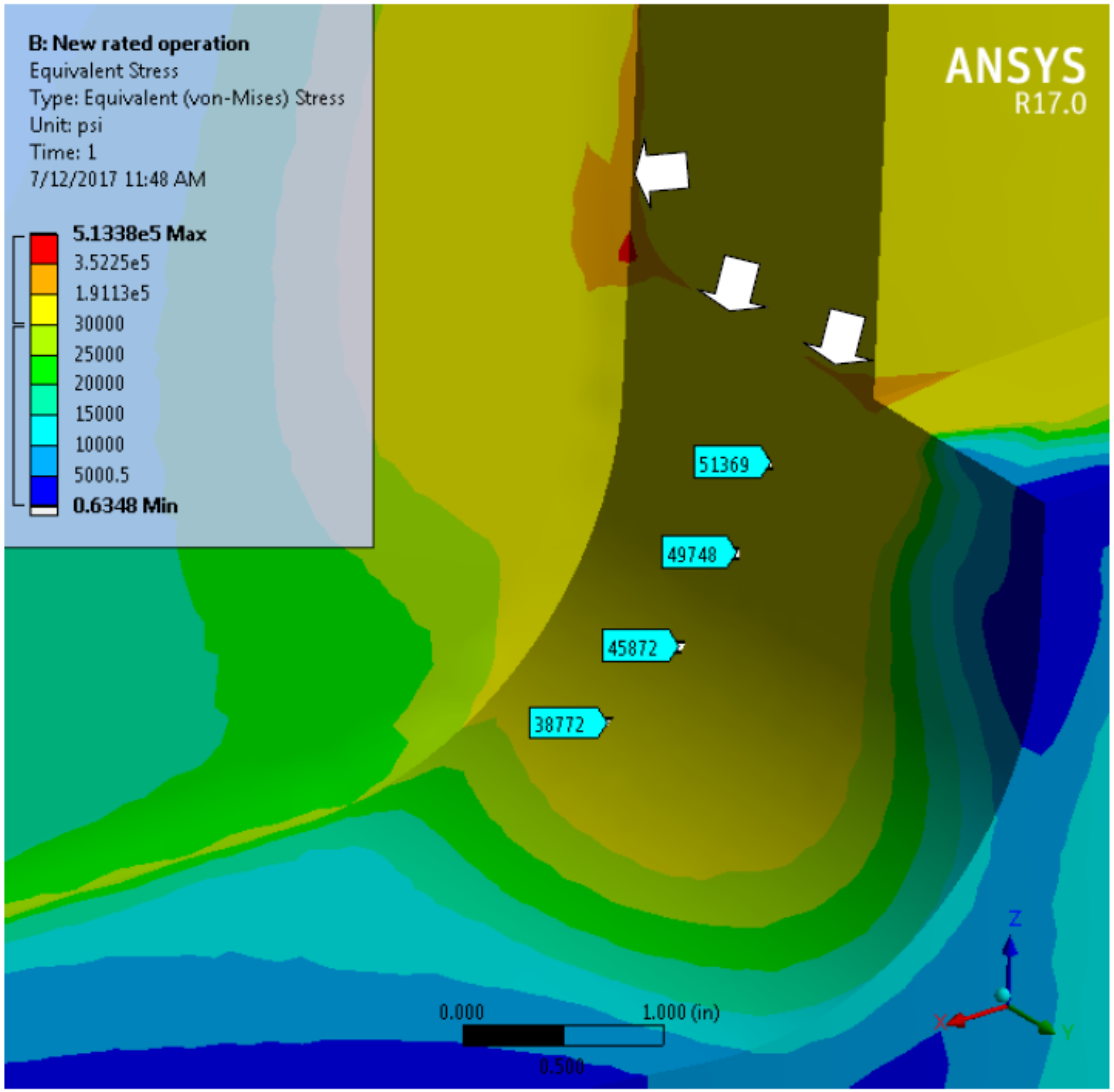


Figure 15: Von Mises stress in bottom of torque keyway at new rated operation.
Local: $\sigma_L + \sigma_b + \sigma_Q = 51\text{ksi} > 0.8 * 1.5\ \sigma_{all} = 24\text{ksi}$.: static stress not acceptable
Note: stresses area sampled from *more than two* elements away from the Displacement Support at the side of the keyway, down to the two white arrows, and so avoid the unrealistic singularities there.
Note: The as-measured main radius in this area is generously sized, so the presence and role of σ_F and fatigue are debatable. Nevertheless, a fatigue check using a principal stress made up largely of $\sigma_L + \sigma_b$ is done for completeness.

Gen shaft FEA at axial thrust keyway

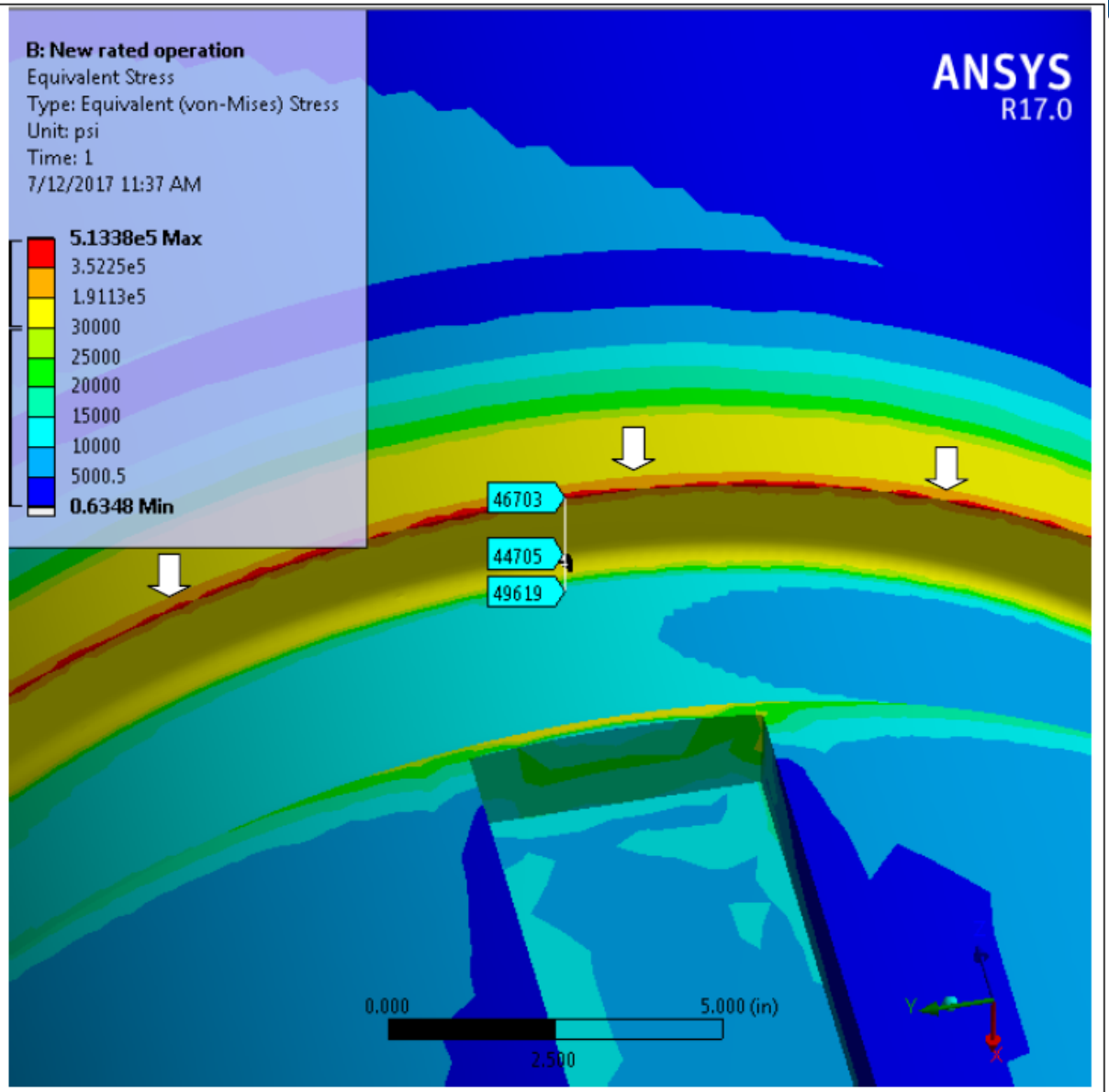


Figure 14: Von Mises stress in top radius of axial thrust keyway at new rated operation.
Local: $\sigma_L + \sigma_b + \sigma_Q + \sigma_F = 50$ ksi > $0.8 * 1.5\ \sigma_{all} = 24$ksi.: static stress not acceptable
→ fatigue analysis required
Note: stresses area sampled from more than two elements away from the Displacement Support at the edge of the keyway (at the white arrows), and so avoid the unrealistic concentrations there.

Gen Shaft Condition Results to Date

Condition assessment not complete. Work started but halted due to other unit issues – B9 Kaplan pipe failure, B8 oil trunnion leak.

- Assessment difficult and requires major disassembly and use of head gates.
- Use of head gates means other plant maintenance can't be performed.

➢ Decision required now because new rotor design on hold pending decision. If new gen shaft, Andritz would use a different connection to the rotor spider.

Gen Shaft Recommendation

Current scope is to disassemble, clean, NDE and dimensional check for approx. $50k.

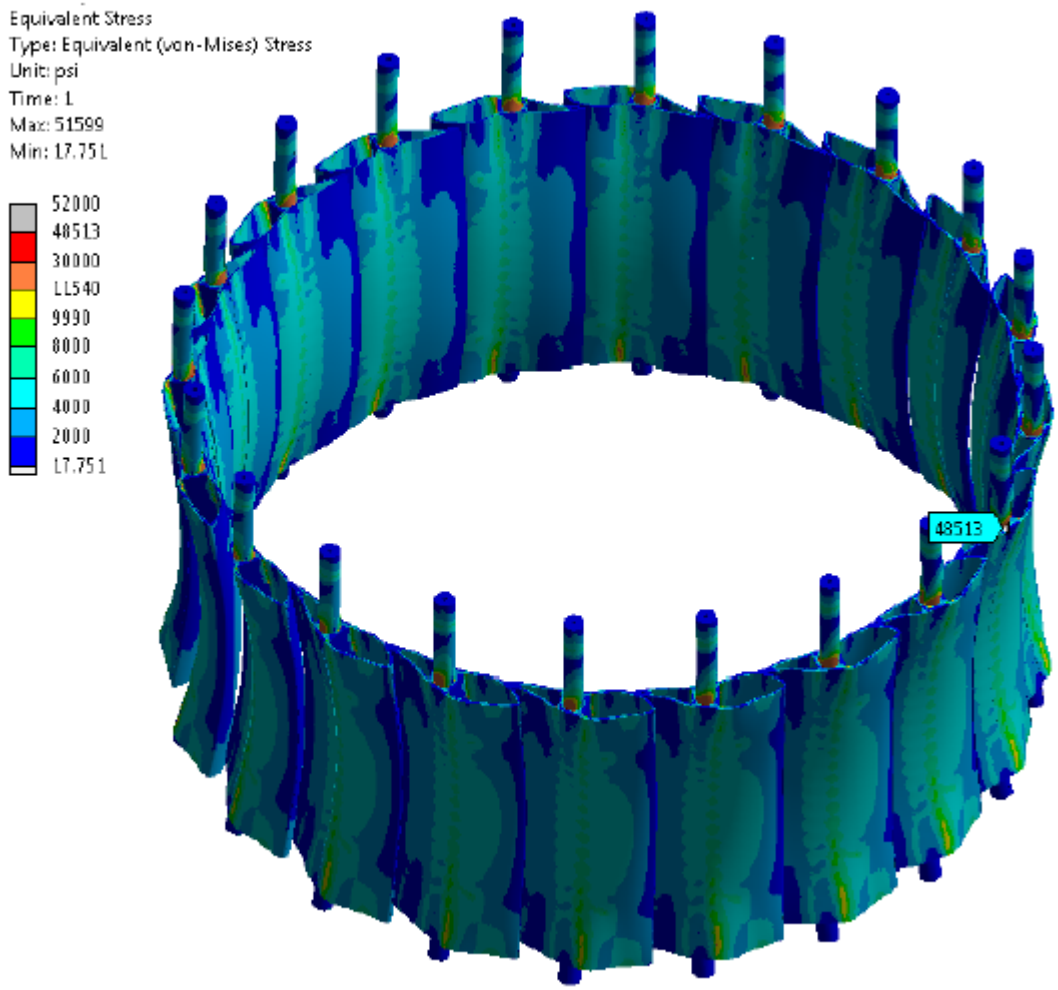
- Contract has option for new gen shaft at $250k per unit additional cost.
- 90% chance that Gen shaft needs remedial machining work at key way – est. at $50k per unit and 2-week duration.
- 20% chance cracks are found that need repair at $30k
- 5% chance gen shaft found not to be usable. If new shaft required delay, it would be about 1 year and overlap the HCP check-in period.

➢ Recommendation – Purchase new gen shaft all 4 units

  – Benefits are that $100k goes to new purchase with full 50-yr life and no schedule impacts.

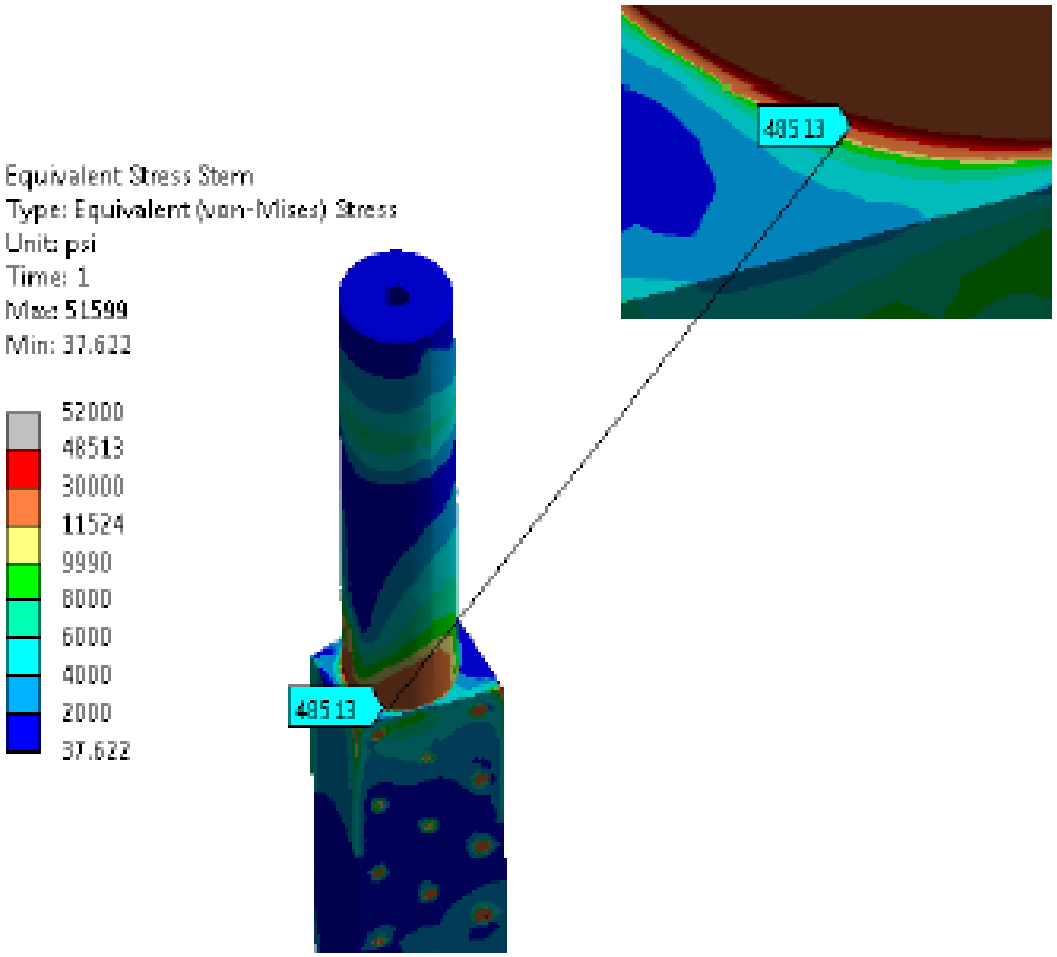
Wicket Gate Stress Analysis

9.1.6 LC1 Wicket Gates Von Mises Stress



Wicket Gate Stem Stresses

9.1.7 Wicket Gate Upper Stem Von Mises Stress



Wicket Gate Condition Results to Date

- Inspections not yet performed - Requires head gates and unit unwatering.
  - Use of head gates means other plant maintenance can't be performed.
  - No dewatering pumps available
  - Plant dewatering system held in reserve for any issues with B6 dewatering system (which had issues in June)

- B4, B3, B1 wicket gates inspected 2009 to 2012 and only a few gates per unit needed repairs.
- B2 in 2014/15 needed 14 of 20 gates repaired that took 3 months and approx. $350k.

Wicket Gate Recommendation

Current scope is to disassemble, clean, NDE, dimensional check replace up to 4 gate sleeves, add stainless steel overlay to all upper and lower stems for approx. $475k per unit.

- Contract has option for new wicket gates at $575k per unit additional cost.
- FEA recommends stem machining est. at $100k per set, which is extra work.
- Extra work also would include crack repair, stem straightening, additional sleeves.
- 50% chance repairs similar to B2 found on the other 3 units ($175k).
- 90% probability gates won't last 50 years.
- 50% chance gates last 20 years.
- Undefined risk – if corrosion fatigue of wicket gates is similar to blades, then all gates may be very near end of life.

➢ Recommendation – Purchase 3 sets of new wicket gates. Reuse B2 wicket gates.
  – Benefits are that $275k goes to new purchase with full 50-yr life and no schedule impacts

Failure Risk

Risk probability:

- New design issue: Low
- Failure of reused components in 50-year life: High

- Collateral damage:
  - Pole comes loose and damages stator ($1M to $3M)
  - Shaft key failure causes rotor to strike stator ($5M)
  - WG stem failure causes gate ring system damage ($1M)

Schedule Risk

Reuse Option: Current schedule will be impacted

- 90% chance of 1 month for repairs
  - 2 weeks to make FEA suggested modifications to WG's
  - 2 weeks of assumed crack and machining repairs to gen shaft and WG's
- 5% chance of 10-month delay due to need for replacement of shaft or WG's.

New Option

- 10% chance of 1 month due to design/manufacturing that causes construction delay.

Financial Evaluation

- Updated future power-related price assumptions
  - IRR = 10.2% compared to 13.9% from Dec. 2016

- Option 1 - Stay with contract scope, spend $1.42 M on repairs and assume forced outage in ~20 years: IRR 9.2%.

- Option 2 - Replace pole bodies, wicket gate and gen shaft now: IRR 9.5%

➢ Recommend Option 2 – For schedule risk and financial benefit replace now.

Recommendation Summary

- Rotor Poles: $750k x 4 = $3 M
- Wicket Gates: $575k x 3 = $1.75 M (reuse B2)
- Generator Shaft: $250k x 4 = $1.0 M
- Total = $5.75 M

Next Steps

Resolution to:

- Revise budget up by $5.75 million.
  - New budget = $70.05 M.

- Contract Field Work Order/Change Order(s) to purchase additional items.

Questions?

Appendix

1) Decision Evaluation Criteria responses

Decision Evaluation Criteria

1. What is the impact on our Customer-Owners?
   - Economic value for project with updated future power-related price assumptions is 10.2%. The recommended option to replace components reduces value to 9.5%.
     - The alternative to defer the spending until failure, which reduces the IRR to 9.2%.
   - Requires incremental capital of $5.75M project cost currently not in the project or District forecast
   - Increased reliability for 50 years with reduced outage time through planned or unplanned failures of fatigued components
   - Supports strategic objective to invest in long-term assets that provide value

Decision Evaluation Criteria

2. What are the stewardship implications and impact to the environment?
   - Provides more certainty that the District will be able to stay on the accelerated schedule designed to complete work in advance of HCP check-in
   - Accelerated schedule reduces risks to successful HCP check-in by having B1-B4 units in service
     - If HCP check-in not successful, introduces potential risks of incremental costs associated with new fish studies and/or spill requirement modifications.

Decision Evaluation Criteria

3. What are the legal implications?
   - Recommendation for new components now does not impact current license and does not impact District's initiative to optimize relicensing efforts.
   - Contract optionality allows the District to modify scope for new components if refurbishment does not provide unit life objectives. Valid until August 15, 2017.
   - Requires Board approval for project scope and budget revision.

Decision Evaluation Criteria

4. What are the workforce/operations implications?
   - Recommended path requires some additional inspections for the new components but less inspections during construction.
   - The alternative to defer the spend will result in an estimated 1 month schedule extension and could result in unplanned resource needs or reprioritization should disassembly reveal worse conditions causing schedule delay or if unplanned failure occurs.

Decision Evaluation Criteria

5. What are the other stakeholder implications?
   - Provides more certainty to power purchases for unit life of 50 years with less risk around unplanned failures or schedule uncertainty.
   - DRC/CRC funds may be exhausted during 5-planning horizon, thus cost-plus power purchasers may be impacted by incremental spend.
   - Fish agencies and HCP would support more certainty around the B1-B4 being complete prior to HCP check-in.
   - FERC license would not be impacted.
   - Customer owners are supportive of strategic objective to invest in long-term value add assets.

Decision Evaluation Criteria

6. What are the impacts to Values?

- Safety: recommendation provides more certainty around equipment condition, future resource requirements and unplanned failures, thus creating a supportive work environment.
- Stewardship: best supports schedule certainty for unit availability during the HCP check-in and recommendation provides incremental value to customer owners versus the risk-adjusted alternative of deferring spend
- Trustworthiness: supports long-term relationships with power purchasers through value creation, avoids uncertainty associated with the alternative, consistent with strategic plan objectives
- Operational Excellence: supports putting the best conditioned units back in service to meet the unit life objective of 50 years with consideration of economics, risk, and resource impacts.