Seattle City Light

Boundary Powerhouse

Thrust Bearing Failures

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3 years @ Skagit Project (SCL)

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2 years @ Boundary Project (SCL)

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ENERGY RESOURCES

- Owned Hydro
- Treaty Rights From British Columbia
- Long-Term Hydro Contracts
  (CBH is the Columbia Basin Hydropower)
- Other Long-Term Contracts

Original Boundary Hydro

250′ Rated Net Head +21′ / - 30′

U51 – U54 Installed 1967
- Design: Bechtel Leedshill
- Generator: G.E. 145 MVA each
- Turbine: NOHAB 208,000 HP @ 120 RPM

Uprated
- U51 – 1982 166.3 MVA, 158.4 MW
- U52 – 1993 170.0 MVA, 161.5 MW
- U53 – 1981 166.3 MVA, 158.4 MW
- U54 – 1979 170.0 MVA, 161.5 MW

U55 & U56 Installed 1986 (~4% larger)
- Design: Harza
- Generator: TOSHIBA 210 MVA each
- Turbine: TOSHIBA 268,204 HP @ 128.6 RPM

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Boundary Hydro Today

<u>U51</u>
Turbine: 2002 Preussag NOELL 210,138 HP
Gen: 2021 Rewind 190 MVA by G.E. Renewable Energy

<u>U52</u>
Turbine: 2000 Preussag NOELL 210,138 HP
Gen: 1993 Rewind 170 MVA by G.E.

<u>U53</u>
Turbine: 2001 Preussag NOELL 210,138 HP
Gen: 2014 (Emergent) Rewind 166.3 MVA by ALSTOM

<u>U54</u>
Turbine: 1999 Preussag NOELL 210,138 HP
Gen: 2023 Rewind 190 MVA by G.E. Vernova

<u>U55</u>
Turbine: 2013 Weir American Hydro 299,000 HP
Gen: 2013 Rewind 252 MVA by TOSHIBA Corp.

<u>U56</u>
Turbine: 2015 Weir American Hydro 299,000 HP
Gen: 2015 Rewind 252 MVA by TOSHIBA Corp.

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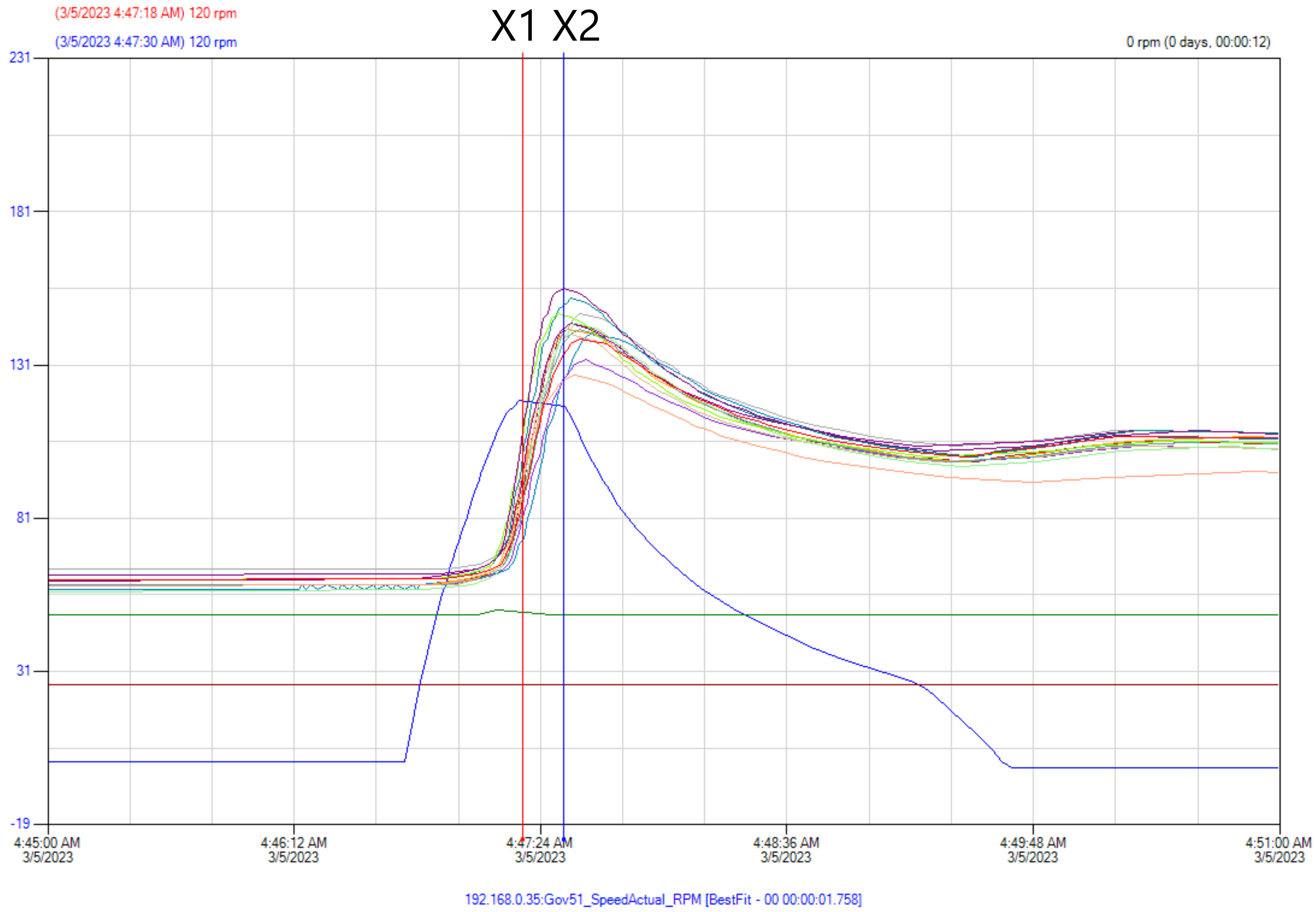
Thrust Bearing Failure Events

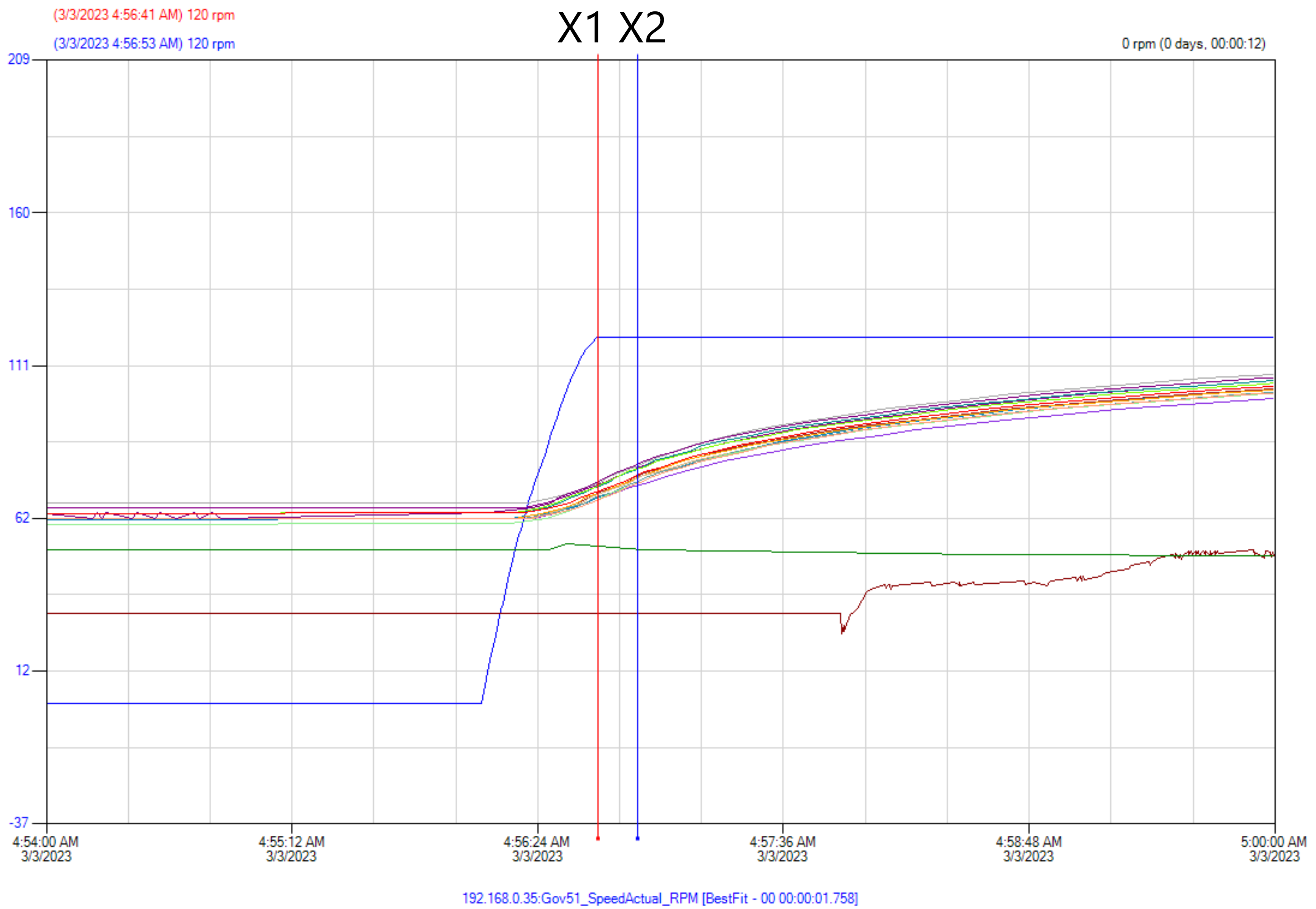
- Rapid bearing shoe temperature rise upon startup, triggering unit shutdown
- U51 – 22 months in service following 2021 generator rehab
- U54 – 2 months in service following 2023 generator rehab
- Units taken out of service for inspection of thrust bearing
- Inspection confirms wiped thrust bearing(s)
- Surface of babbitt reaches melting temperature and is smeared across the surface of the shoe. Flakes of solidified babbitt scatter the oil pot.
- Babbitt is a white metal alloy consisting of mostly Tin, some Copper and Antimony. It can also contain Lead and Arsenic depending on the grade.

Thrust Bearing Temp. Trend During Startup [wipe]



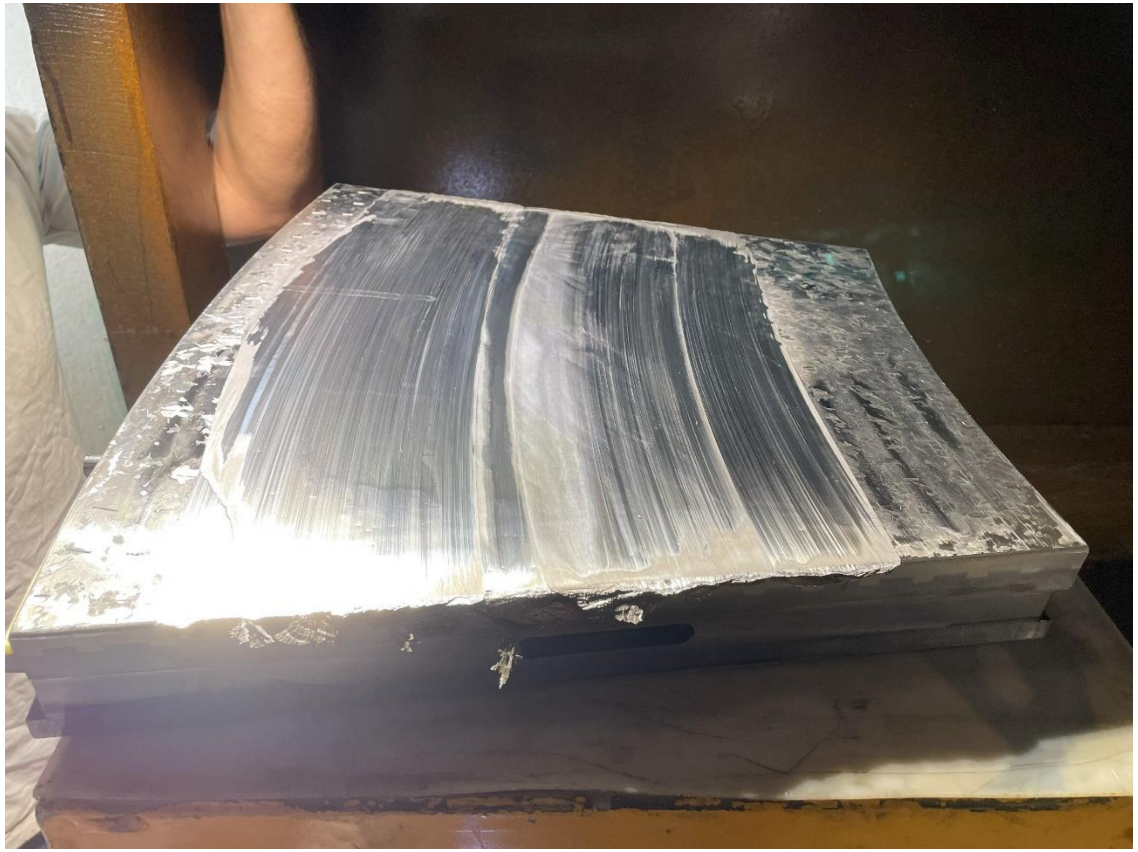
Description	Number	Color	Units	Value at X1	Value at X2
Gov51 - SpeedActual RPM	1		rpm	120	120
Meter51_MW	2		MW	0	0
RTD_U51_GTB_OIL_1_PV	3		℃	31	30
RTD_U51_GTB_1_PV	4		℃	44	76
RTD_U51_GTB_2_PV	5		℃	52	85
RTD_U51_GTB_3_PV	6		℃	53	85
RTD_U51_GTB_4_PV	7		℃	46	76
RTD_U51_GTB_5_PV	8		℃	52	84
RTD_U51_GTB_6_PV	9		℃	48	83
RTD_U51_GTB_7_PV	10		℃	49	85
RTD_U51_GTB_8_PV	11		℃	54	86
RTD_U51_GTB_9_PV	12		℃	50	84
RTD_U51_GTB_10_PV	13		℃	57	90
RTD_U51_GTB_11_PV	14		℃	56	76
RTD_U51_GTB_12_PV	15		℃	63	89
RTD_U51_GTB_13_PV	16		℃	62	94
RTD_U51_GTB_14_PV	17		℃	50	81

Thrust Bearing Temp. Trend During Startup [normal]



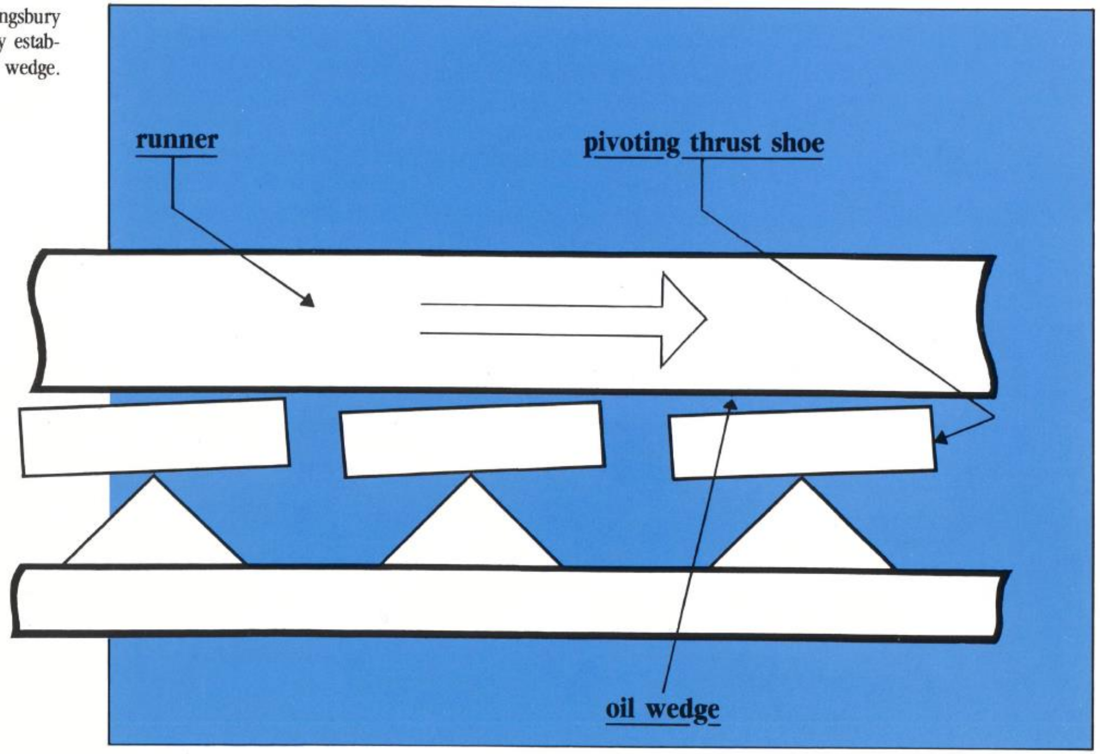
Description	Number	Color	Units	Value at X1	Value at X2
Gov51 - SpeedActual RPM	1		rpm	120	120
Meter51_MW	2		MW	5	5
RTD_U51_GTB_OIL_1_PV	3		℃	32	32
RTD_U51_GTB_1_PV	4		℃	40	43
RTD_U51_GTB_2_PV	5		℃	41	45
RTD_U51_GTB_3_PV	6		℃	41	44
RTD_U51_GTB_4_PV	7		℃	40	43
RTD_U51_GTB_5_PV	8		℃	41	44
RTD_U51_GTB_6_PV	9		℃	41	44
RTD_U51_GTB_7_PV	10		℃	43	47
RTD_U51_GTB_8_PV	11		℃	43	46
RTD_U51_GTB_9_PV	12		℃	40	43
RTD_U51_GTB_10_PV	13		℃	43	46
RTD_U51_GTB_11_PV	14		℃	40	43
RTD_U51_GTB_12_PV	15		℃	43	46
RTD_U51_GTB_13_PV	16		℃	44	47
RTD_U51_GTB_14_PV	17		℃	42	45

Thrust Bearing Wipe

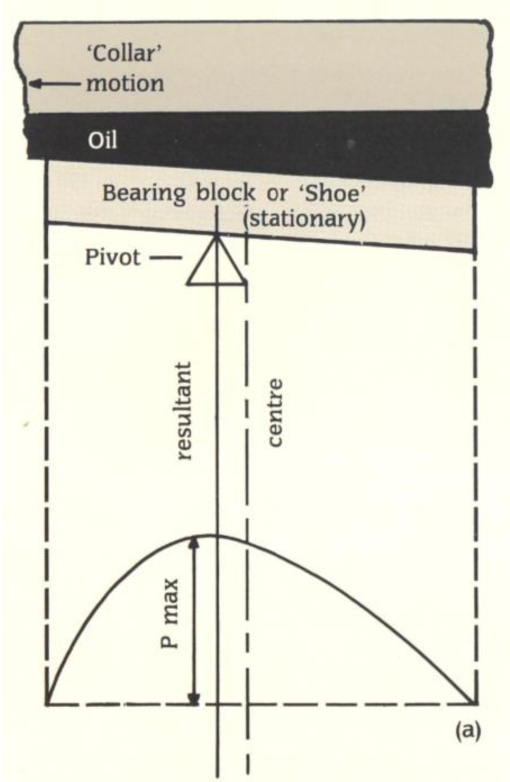


Kingsbury-Michell Tilting Pad Thrust Bearing

This illustration shows a Kingsbury Thrust Bearing automatically establishing an oil wedge.



From Kingsbury, Inc. Catalog, year unknown

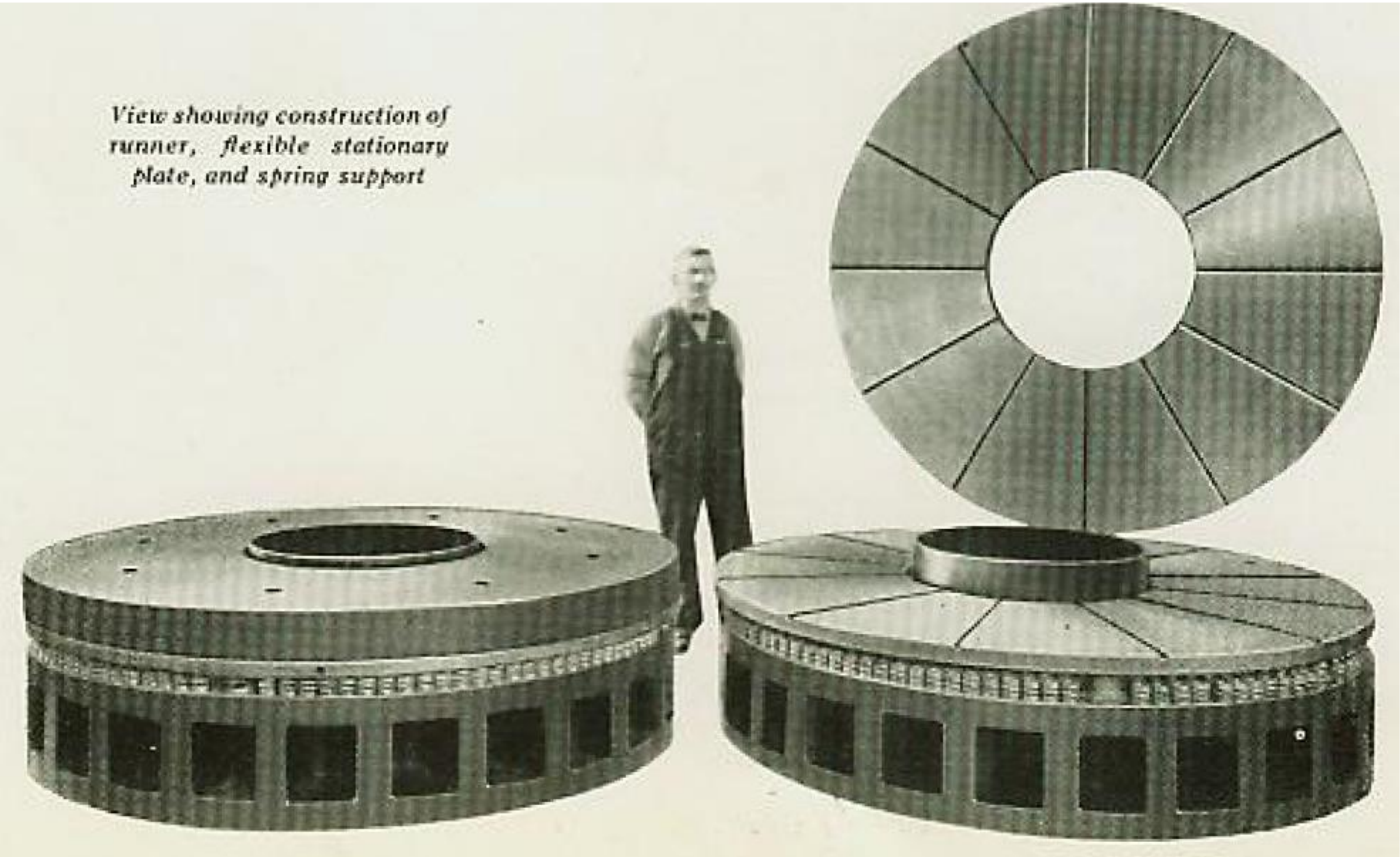


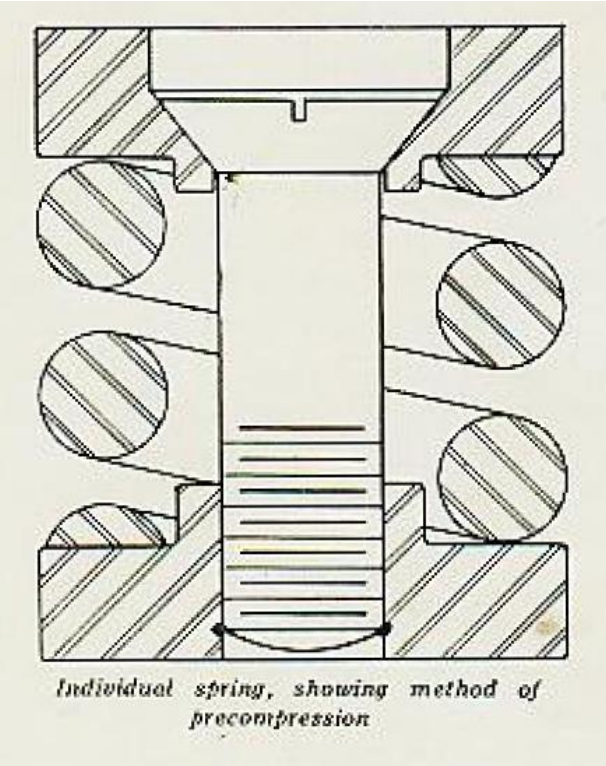
ASME CATALOG ID # HH 0587 1987

<u>Patenting of the Kingsbury thrust bearing Wiki)</u>

Kingsbury tried to file for a U.S. patent during 1907. His initial application was rejected as a British patent had been granted in 1905 to A.G.M. Michell who had a similar concept.[1] Kingsbury was able to demonstrate that his 1898 test at the University of New Hampshire predated Michell's work, so in 1910 Kingsbury was awarded US patent No. 947242 for the tilting pad thrust bearing.[1][3]

G.E. Spring Bed Equalizing



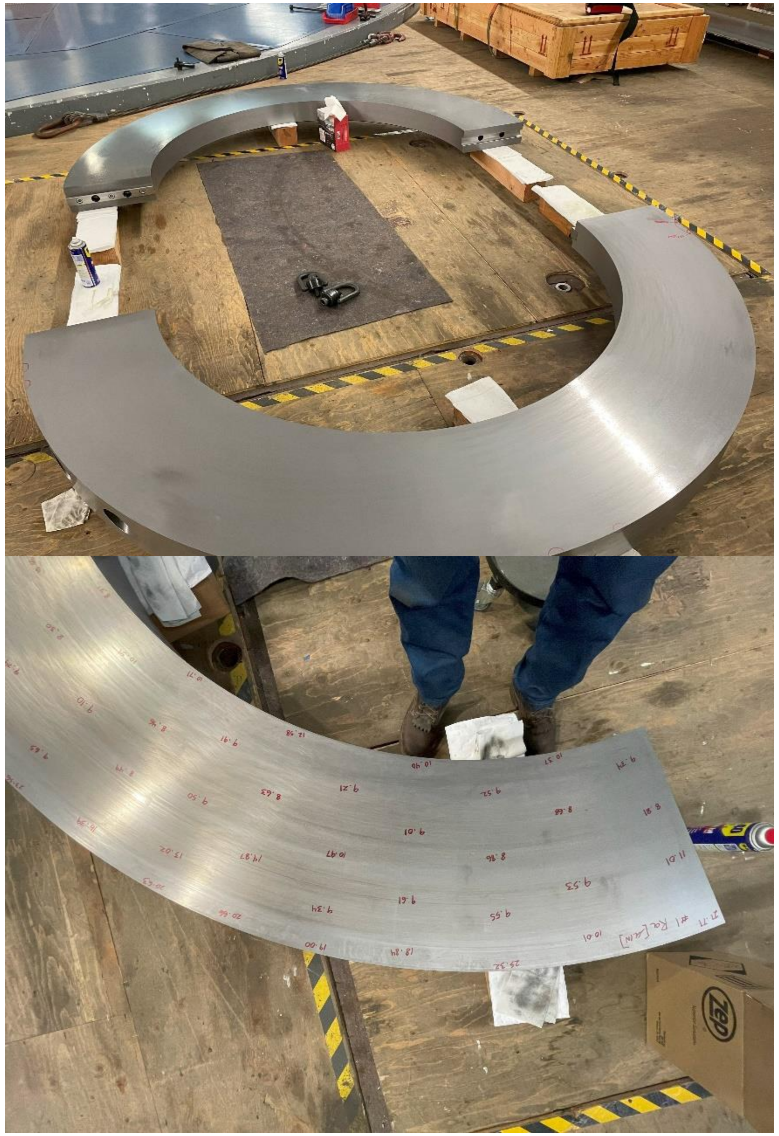


Possible Contributing Factors

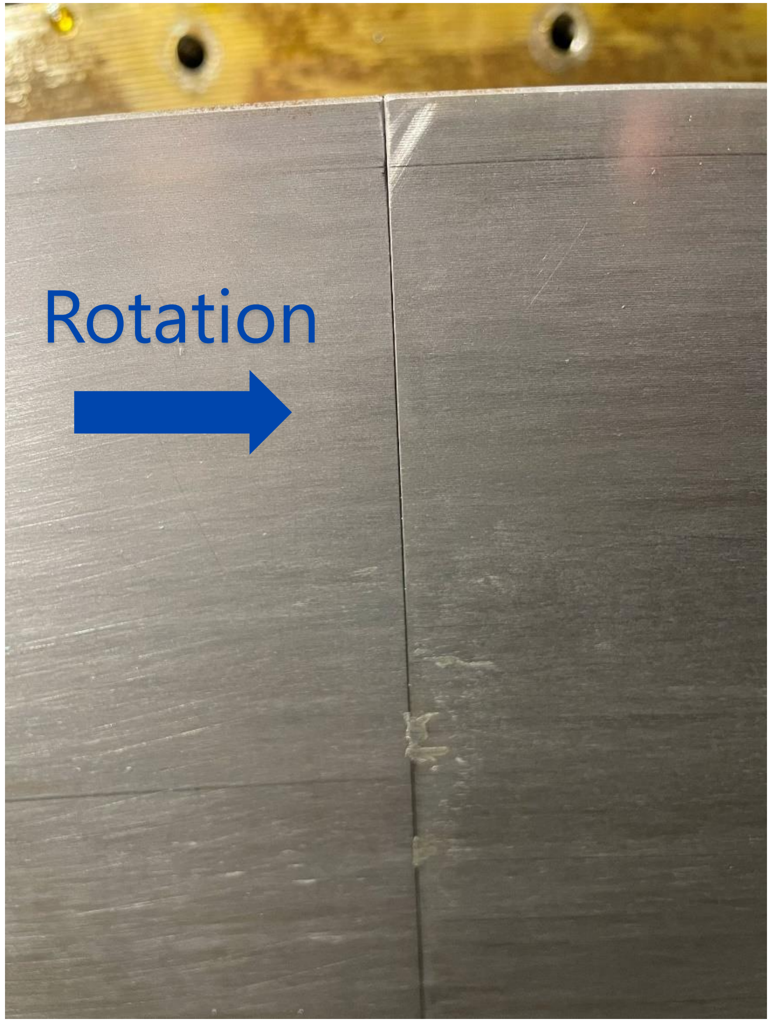
- Thrust runner surface finish
- Thrust block mating surface / thrust runner split lines
- Bearing shoe surface condition
- Increased bearing load
  - Uprated unit → more hydraulic downthrust
  - Heavier rotor due to new spider design
- No high-pressure oil injection system
- Oil weight → ISO 32 vs. ISO 48 (minimal reduced oil film thickness)
- Axial vibrations → no substantial indications of destructive forces

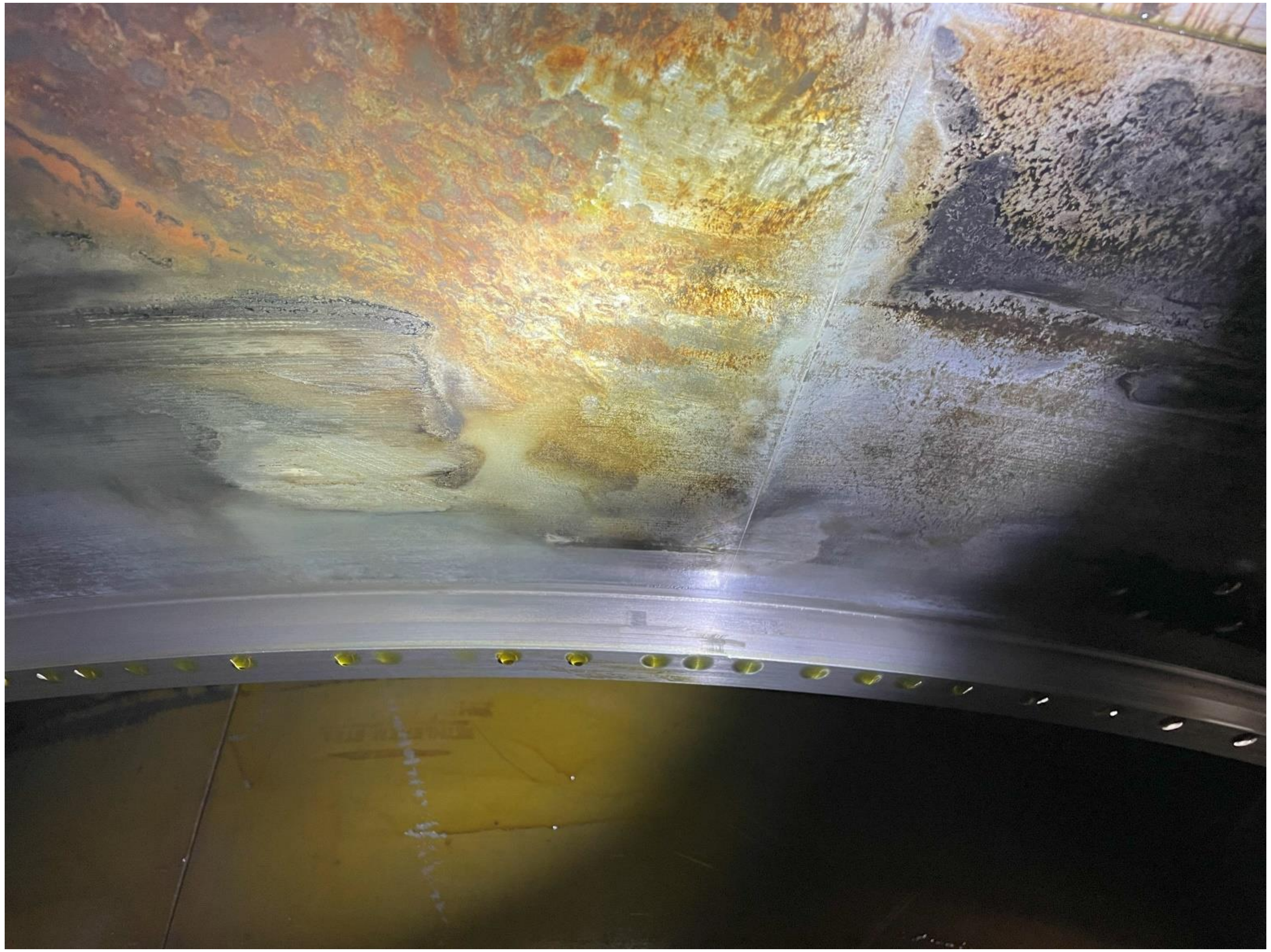
110” x 75” Thrust Runner Surface Finish

- Original thrust runners were cast steel
  - Original G.E. Running Surface Finish Spec. → 4 µin Ra
  - New G.E. Running Surface Finish Spec → 8 – 16 µin Ra
  - U51 O.E. thrust runner shipped to Kingsbury for rehab and no as-found surface data available due to poor packaging
  - U51 rehab resulted in areas as high as 25 µin Ra (Roughness Average) located near center of running surface – SCL accepted
  - U54 O.E. thrust runner as found 3 – 5 µin Ra; Shipped to Kingsbury for rehab due to running surface defects and extensive fretting on mating surface
  - U54 rehab reported 9 – 15 µin Ra running surface finish, but areas near OD were measured as high as 27 µin Ra after wipe.
- New thrust runners are forged resulting in more homogeneous material grain structure



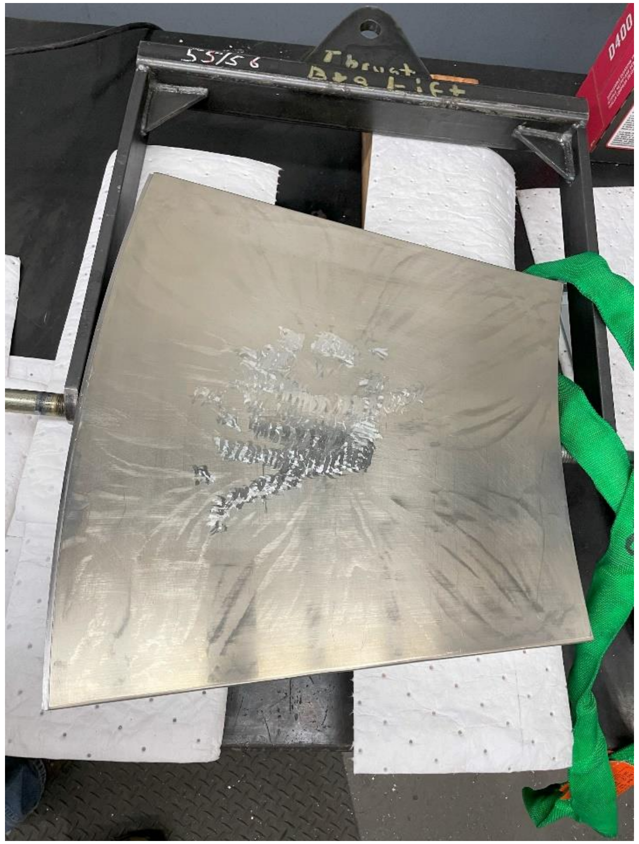
Thrust Runner Split Joints





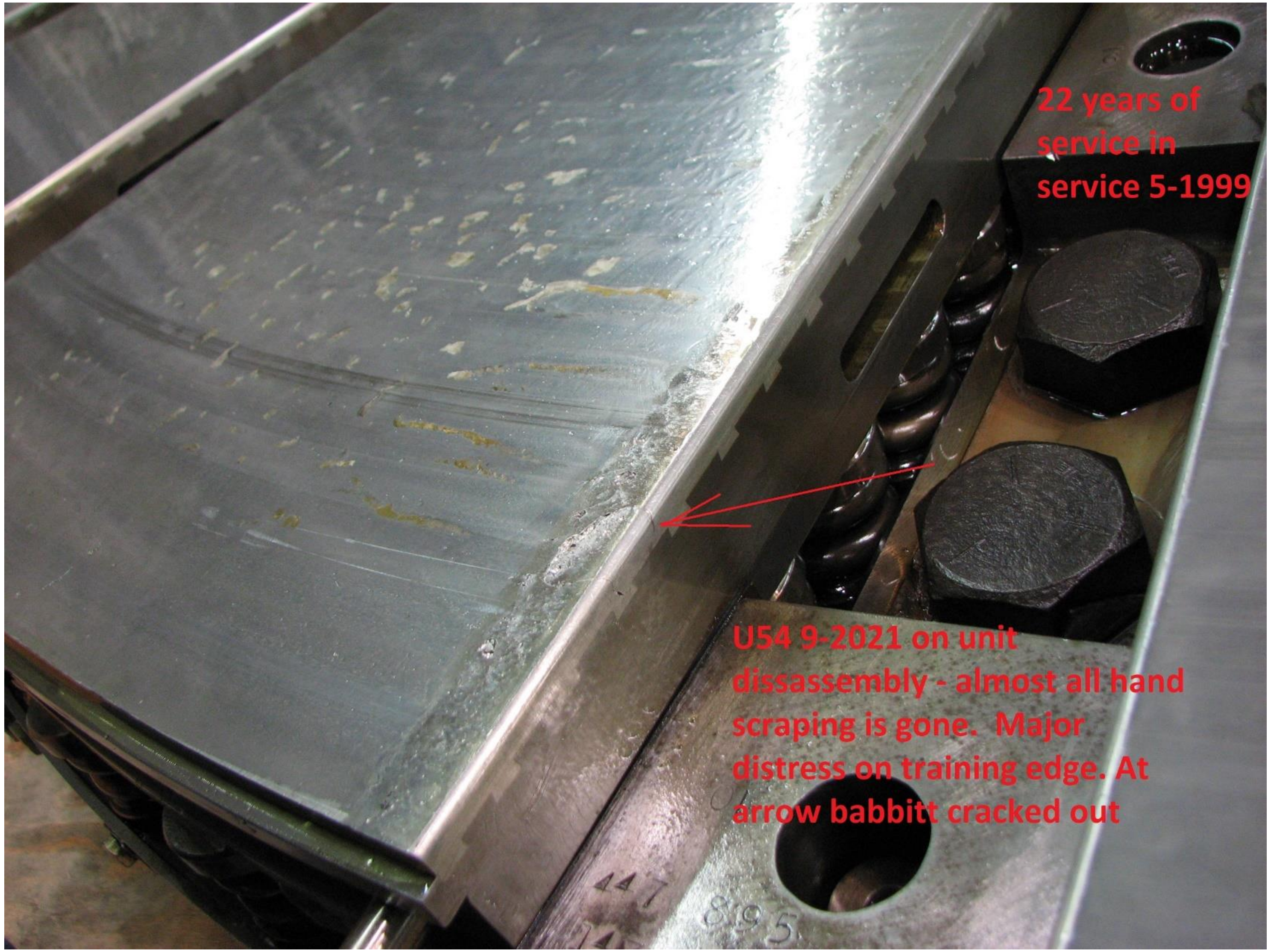
Babbitt Bearing Surface (scraping)

- Both U51 and U54 had conventional bearing scraping, as well as non-conventional scraping pattern



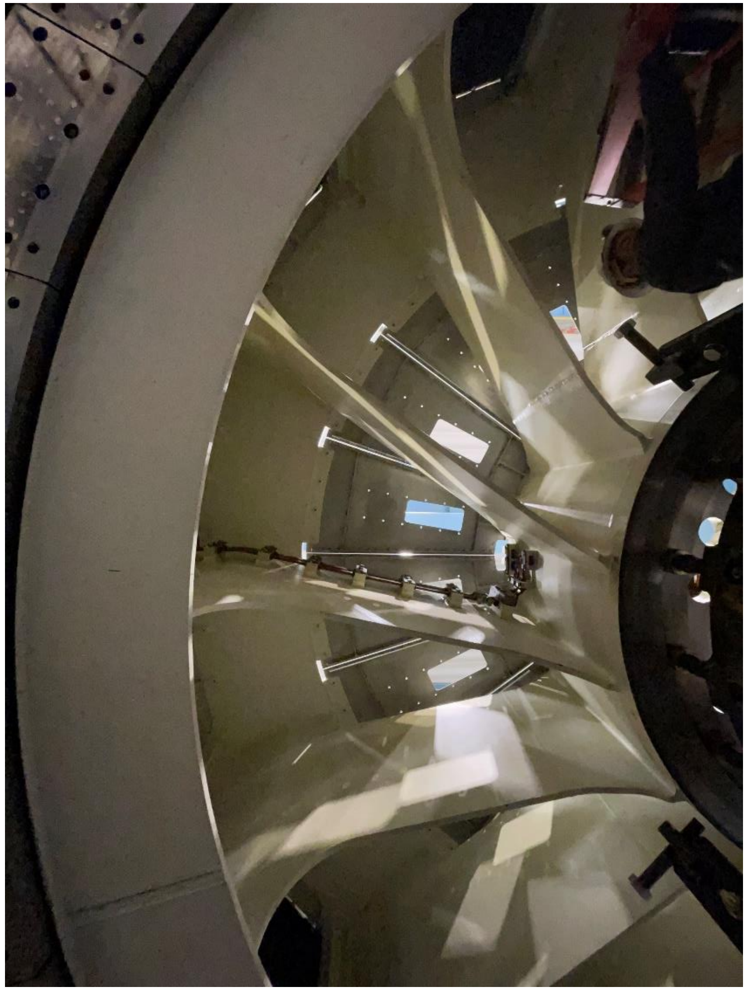
O.E. Bearing with 22 Years of Service

- Note: No high-pressure oil injection system included with original bearing design
  - Failures occurred on startup
  - Jacking was used to flood bearing prior to startup
  - Over the years, duration between startups that requires jacking was extended



Increased Bearing Load

- O.E. Rotor spider replaced with G.E. oblique spider arm design due to issues with floating rim and rotor rim ledge fatigue
  - New rotor design 705,772# → 3.65% increase rotor mass (G.E.), 7.06% increase according to our crane load cell
- Increased Transient Hydraulic Downthrust (1,050,000 lbf)
  - Unit uprated from 165 MVA to 190 MVA → Hydraulic Limitations vs. Electrical Limitations
    - Hydraulic surging at upper end (above 160 MW. More transient bearing load data needed to develop a Gross Head vs. MW curve)
  - In operation, nominal peak pressures of 2.5 to 3 times the bearing unit load are common
  - Specific Pressure → 563 PSI (600 PSI is considered the upper limit for Babbitt)



Repair and Modifications

- New Thrust Runners
  - Rotate / clock runner on shaft so thrust runner split lines do not align with old location on thrust block with localized fretting corrosion
- Add High Pressure Oil Injection System (High-Lift)
- Optimized Bearing Spring Bed Distribution
- Polymer Bearing (PEEK)

  - Repair Timeline: One spare thrust runner and one spare set of re-babbitted bearing pads on hand. Interim repair completed on U54 right away, including spring bed modification. U51 sat out of service for about one year waiting manufacture of new bearing pad, thrust runner and high-pressure oil lift pump skid.

New Thrust Runners

- Original spare thrust runner not acceptable
- Original cast thrust runner refurbishment found to be unfeasible due to thin hardened "chill layer"
- New thrust runners are of forged steel
- Repeat challenges with quality assurance issues with new runners, mainly shipping & handling damage, environmental exposure

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High-Pressure Oil Injection

- 2500 psi MAWP
- 10 HP Motor

Optimized Spring Distribution

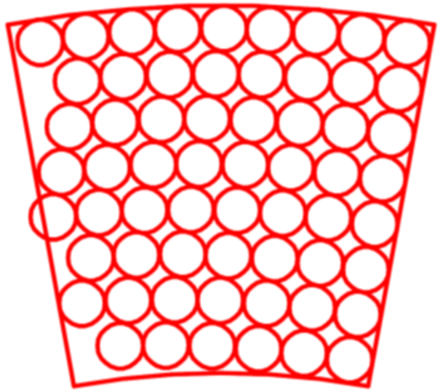
Main results

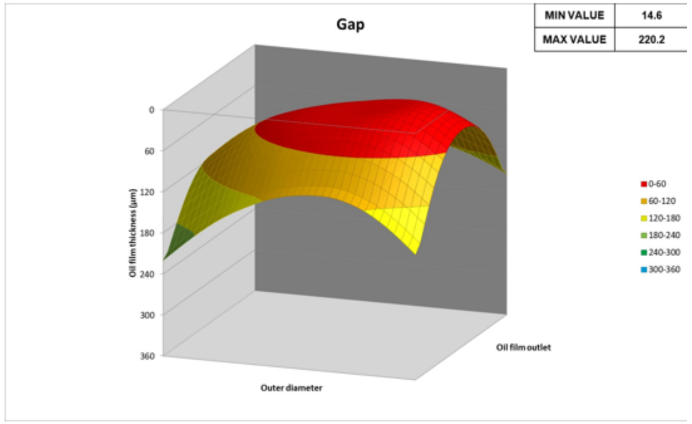
Springs configuration

Oil film Gap

Parameter	Value	Unit
Minimum oil film thickness	14.6	um
Maximum oil film temperature	81.9	°C
Specific pressure	3.62	MPa
Power losses	118.5	kW
Radial support pos.	0.513	-
Tangential support pos.	0.502	-

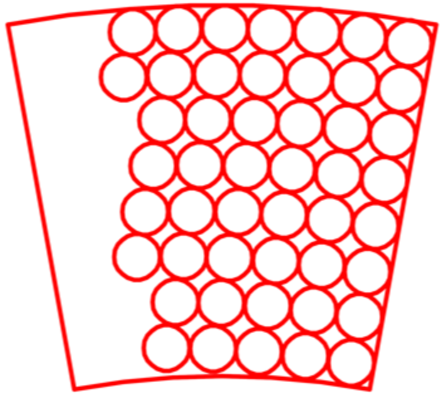
61 springs

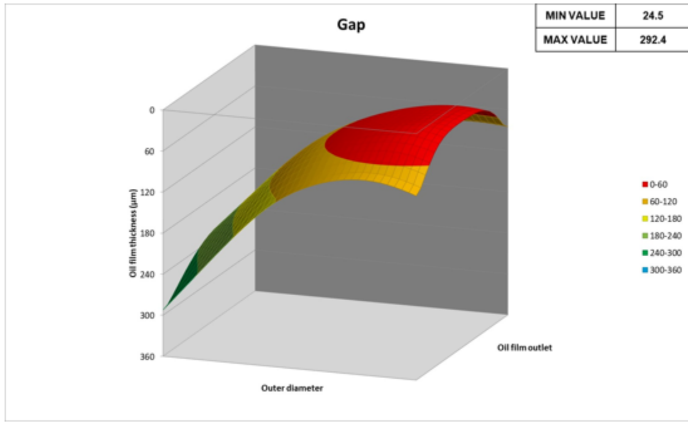




Minimum oil film thickness	24.5	um
Maximum oil film temperature	75.1	°C
Specific pressure	3.62	MPa
Power losses	124.7	kW
Radial support pos.	0.514	-
Tangential support pos.	0.615	-

48 springs





Optimized Spring Distribution (continued)

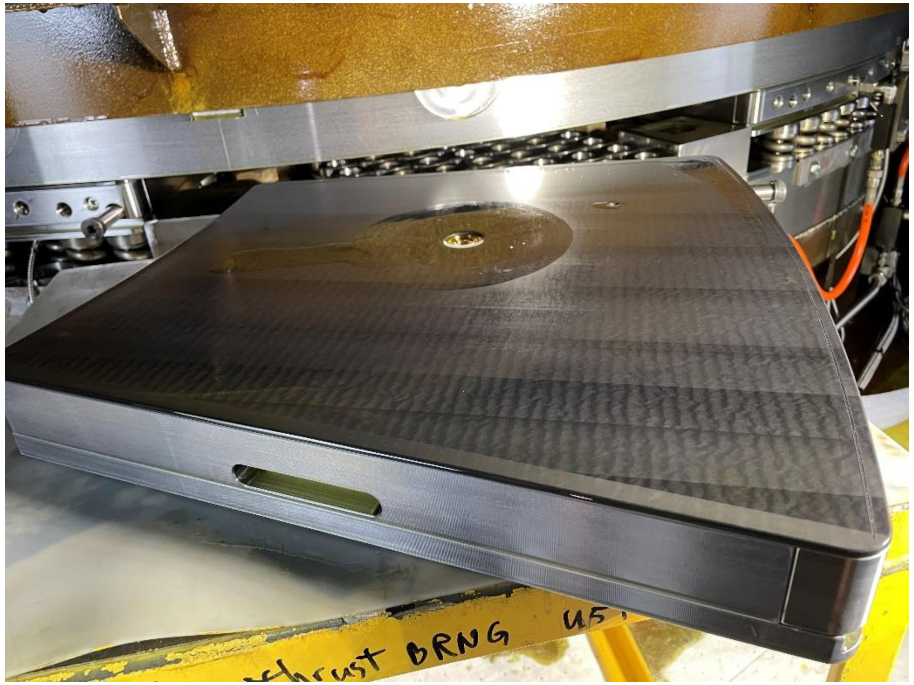
- Spring pattern can significantly affect the operating oil film thickness for spring supported thrust bearings
- G.E. self-equalizing thrust bearing membrane technology retrofit was not feasible due to constraints in elevation / overall height of bearing

PEEK Bearing (Polyether ether ketone)

Trademark:

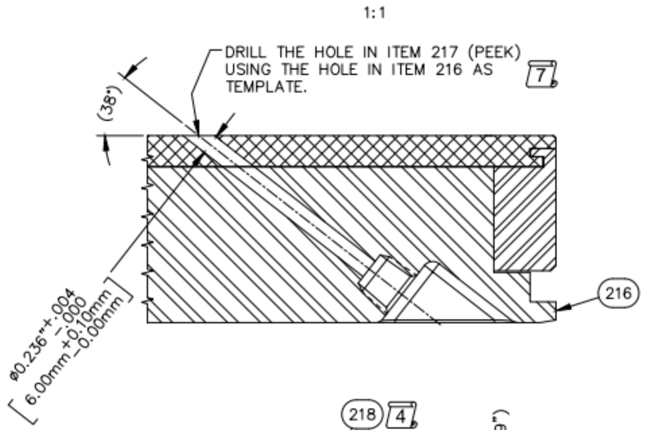
Victrex TDS 450FC30

Highly Loaded Bearing Proven at Porjus Hydro Power Station in Northern Sweden



PEEK Bearing Benefits

- Increased Safety Margin Benefits Compared to Babbitt
  - Higher temperature operations
  - Higher specific loads and speeds → Shown to operate safely at specific pressures above 1450 psi (10 MPa)
  - Reduced friction
  - Reduced thermal deformations (crowning) due to thermally insulating and elastic properties → more uniformly distributed hydrodynamic pressure profile reducing pressure peaks within oil film
  - Lower wear rate by an order of magnitude
  - Proved to be more forgiving without a catastrophic failure mode
  - Increased allowable thrust runner surface finish → 32 µin max. vs. 16 µin max.
  - Ease of replacement of PEEK insert
- Challenges
  - RTD installation with spring bed. RTD now measures oil film temperature vs. temperature of metal base. G.E. design on a new bearing would use thermocouples.
  - Polymers do not give off elemental signature for oil analysis. Instead, rely on particle count and oil filter analysis for oil/bearing health indicator



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THANK YOU


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