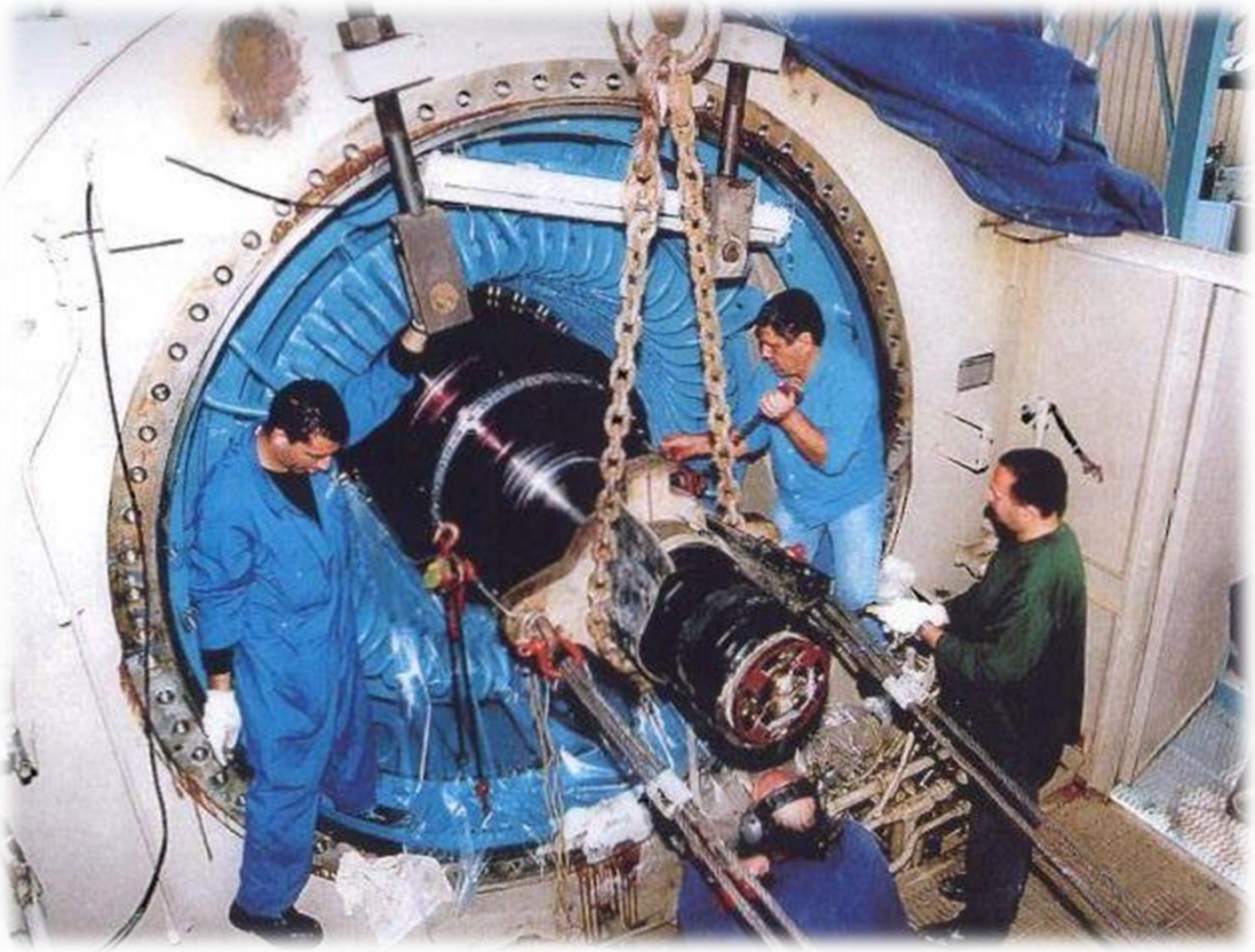
A 30 Years Reliability Survey of a Generator Family



Relu ILIE

Iris Rotating Machine Conference

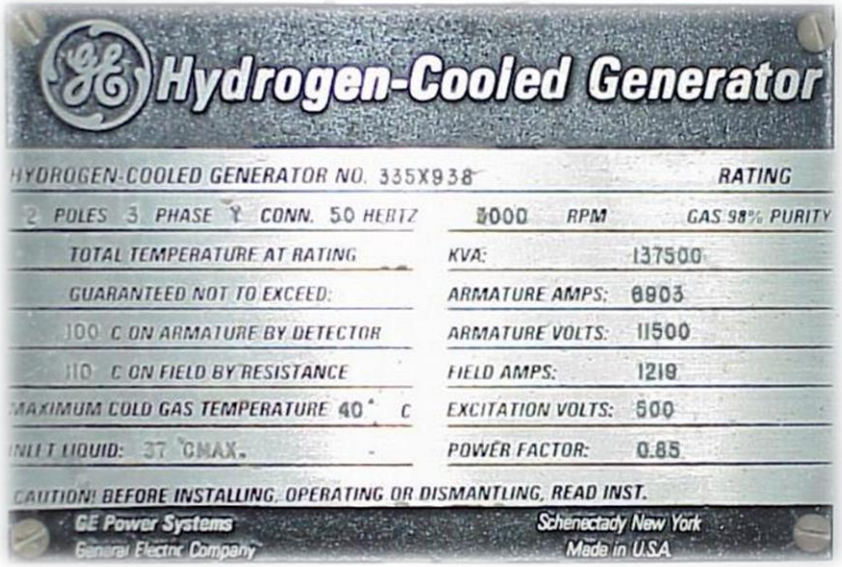
June 24, 2021

Purpose

- Reliability survey of 12 generators type 9H2 over about 30 years. Accumulated 350 unit-year represents a large statistical population
- The purpose is to preserve the history of this generator family, 10 units being sold as per Government’s structural changes
- Generators driven by GE 9E-class gas turbines. More than 3000 frame 9E/7E units installed around the world in the last 40 years
- 50 Hz generators type 9H2 comparable to 60 Hz generators 7H2, but 7E units have 20% higher speeds, 9E have 40% higher outputs

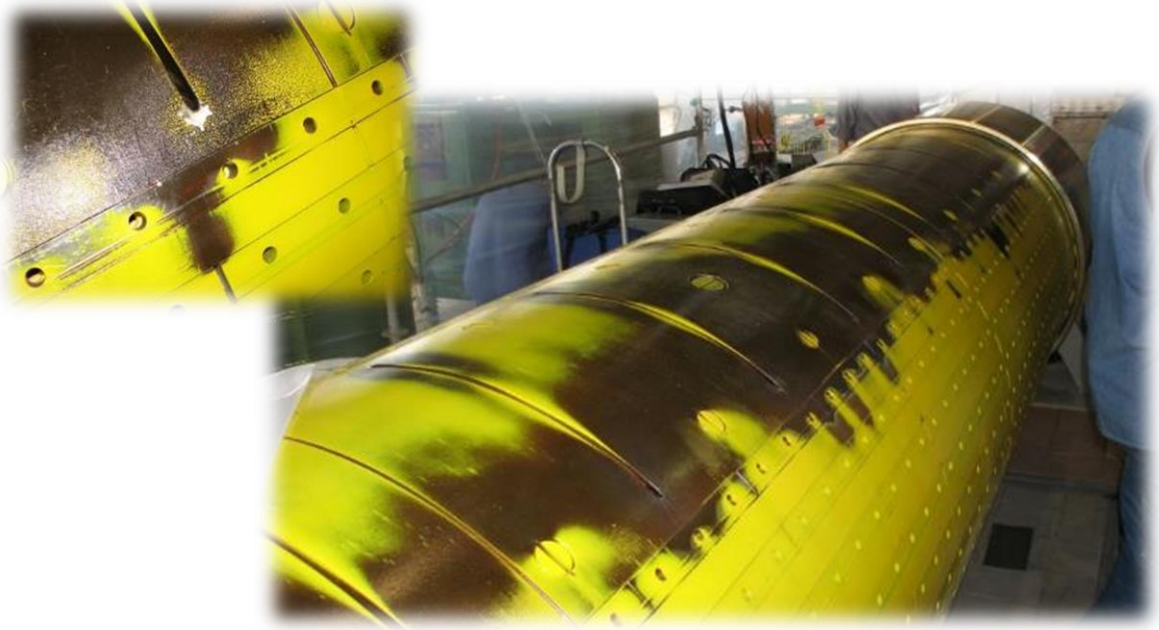
Features

- Hydrogen cooled generators 11.5 kV, almost identical in their design and dimensions
- Slightly different rating according to install year:
  - 6 rated 133.75 MVA (ANSI C50), 1989-1992
  - 4 rated 137.50 MVA (ANSI C50), 1993-1994
  - 2 rated 148.50 MVA (IEC 34), 1996
- Armature and field windings insulation class F designed for class B temperature rise
- ANSI C50.15 starting frequency 500 starts/year



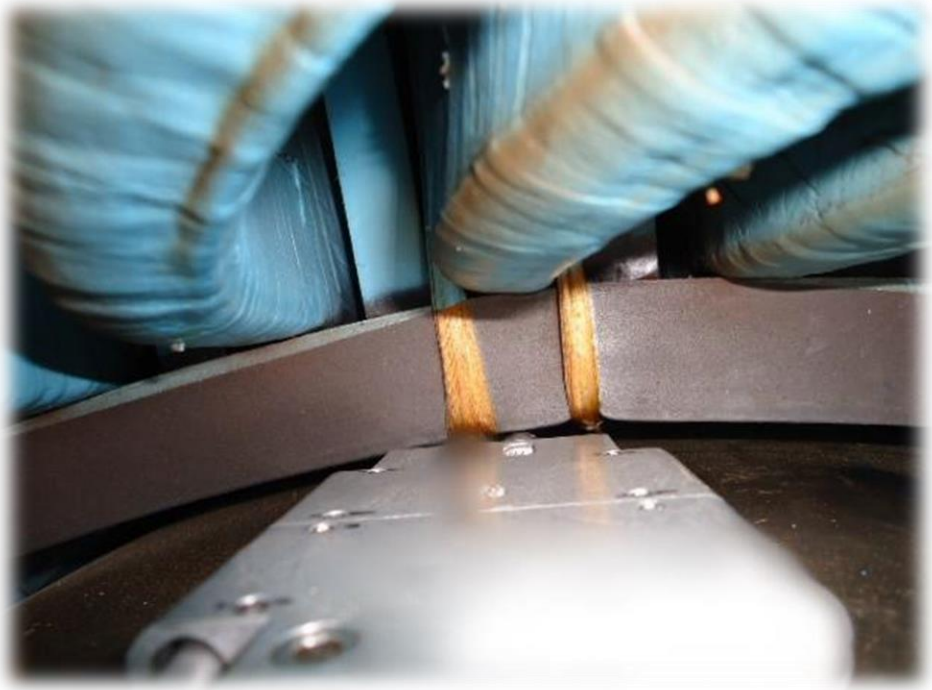
Operation

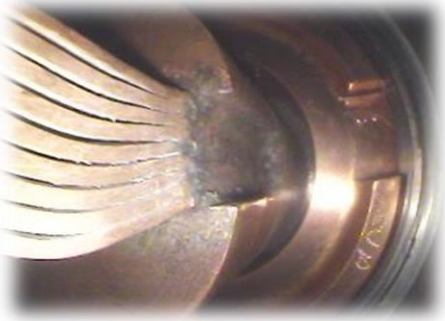
- Initially all 12 in open cycle. Later, 6 units integrated in 3-shaft combined cycle
- Initially all 12 burned distillated oil. Later, 8 units converted to natural gas
- Operated in two-shift: ~100 starts/year for open cycle, ~200 starts/year for CC
- Typical signs of negative-sequence event (unreported) found in one rotor
- A couple of seal-oil ingress incidents occurred, without direct consequences



Maintenance

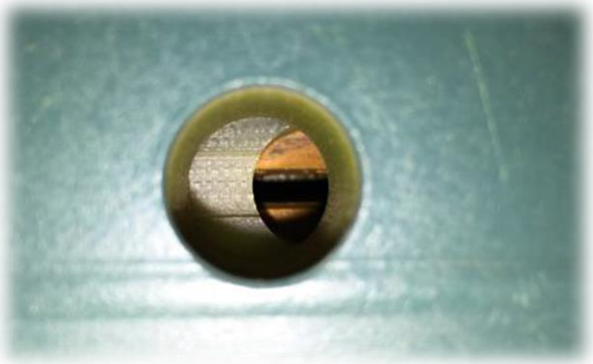
- Initially rotor-out outage performed during turbine major inspection acc. to O&M book
- Later on, maintenance updated according to OEM’s documents and user’s procedures
- Major outage at maximum 12 years intervals, exceptions for system / budgetary constraints
- Every generator passed during the years two rotor-out and several borescope inspections
- One unsuccessful robotic inspection attempt





Rotor Issues

- **Creepage block migration**
  - Blocked cooling vents induced thermal sensitivity and abnormal vibrations
  - Appeared in 6 generators, as soon as after 1400-1800 starts or 10-13 years
  - In severe cases of blocked cooling passages the solution was full rewind

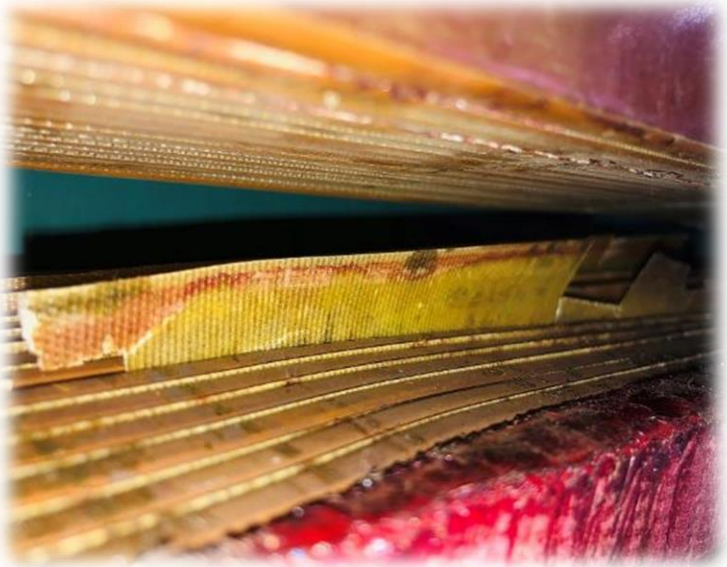


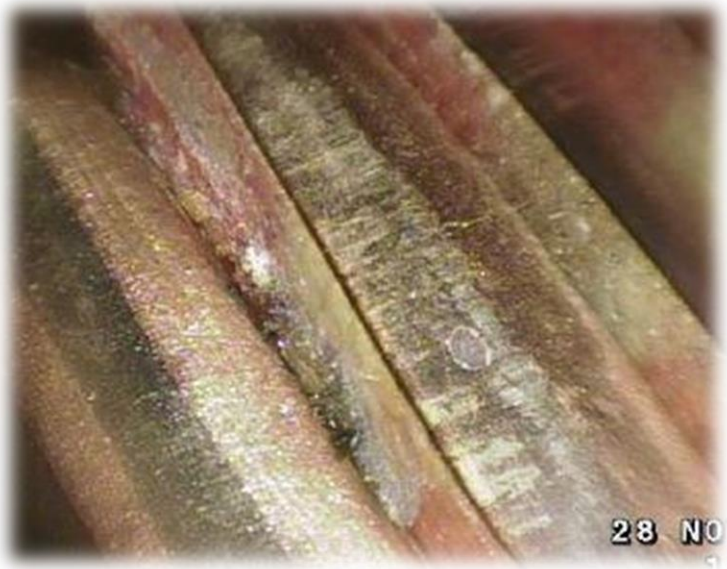
Rotor Issues

- **Terminal stud leaves**
  - Cracked / broken copper leaves may lead to excitation circuit interruption
  - Occurred in 4 generators, as soon as after 1100-1500 starts or 5-7 years
  - Once tripped loss-of-field relay. Solution: replacing the stud (partial rewind)

Rotor Issues

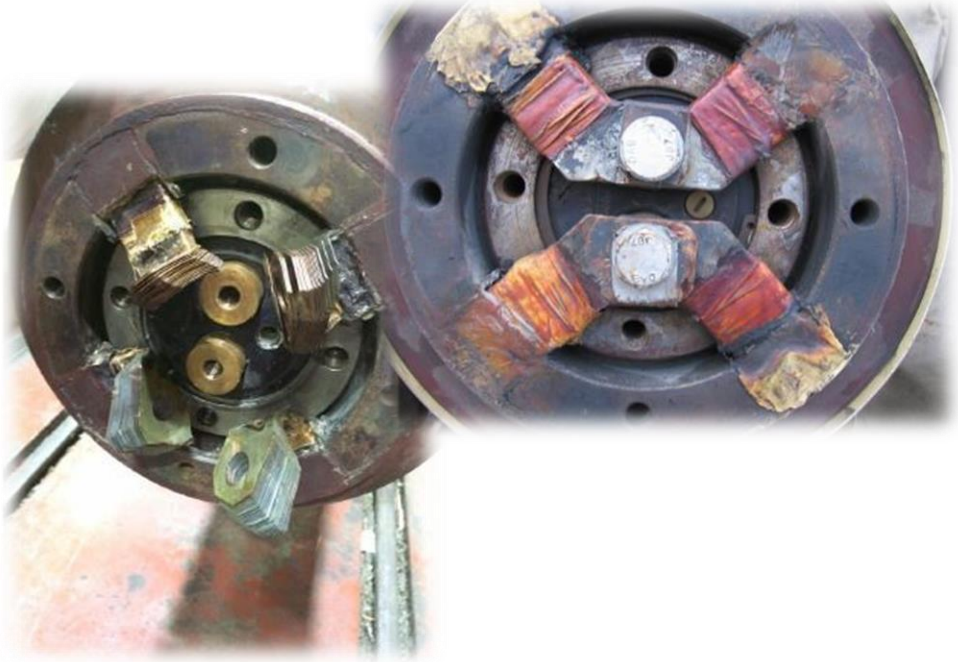
- **Dislocated turn insulation**
  - In the end-winding, may lead to shorted turns and thermal sensitivity
  - Found in several machines, for instance after 2200 starts and 11 years
  - Can be only addressed during a partial or complete rewinding work

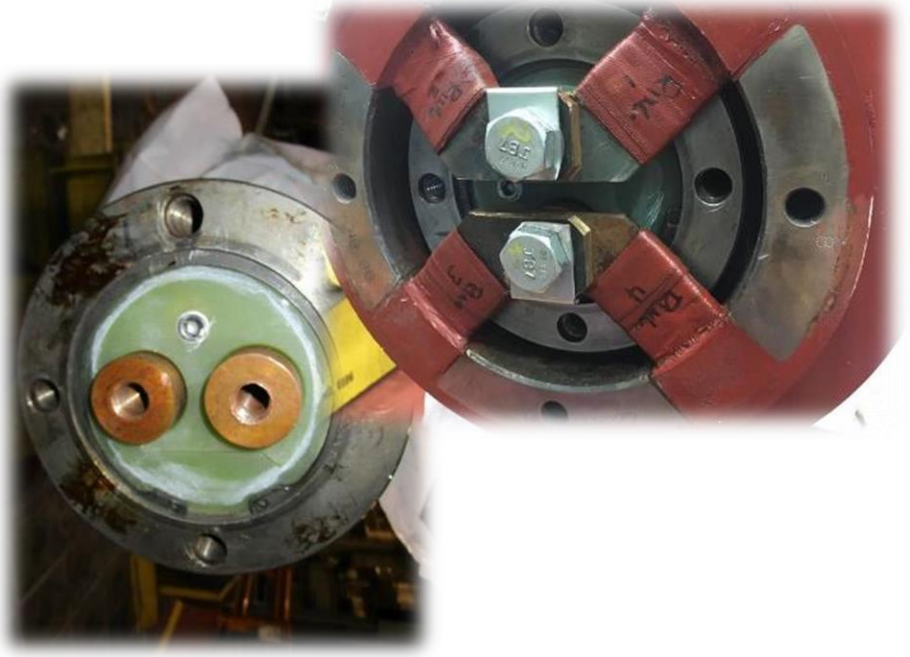




Rotor Issues

- **Collector leads insulation**
  - Damaged +/- insulation may lead to ground faults or be related to H_2 leaks
  - 3 occurrences, e.g. after 2300 starts (12 years). Once tripped ground relay
  - In some cases can be repaired in the field, in others rewind necessary



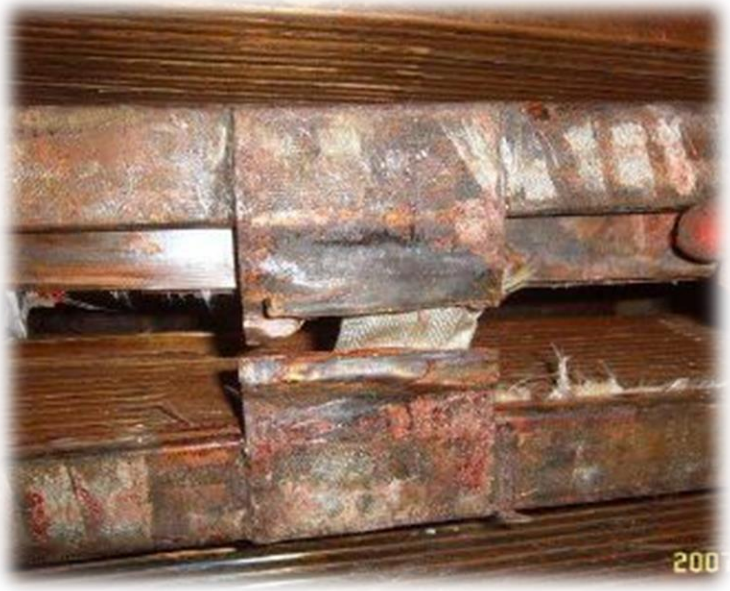


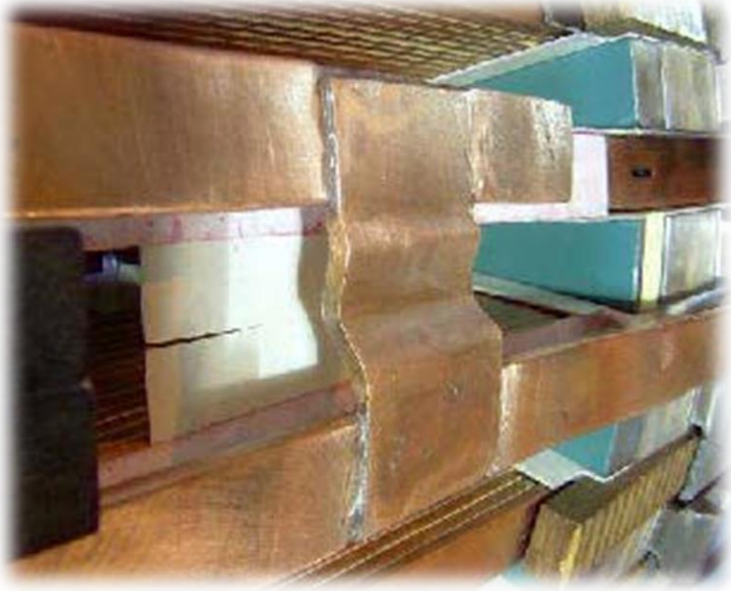
Rotor Issues

- **Shorted turns or coils**
  - May lead to thermal sensitivity and vibrations
  - Shorted coils case after 1500 starts (15 years), following copper deformation
  - Shorted turns case after 2500 starts (14 years) because damaged interturn insulation

Rotor Issues

- **Pole crossover event**
  - Broken pole-to-pole connector resulted in loss-of-field protection trip
  - Occurred after 2800 starts and 14 years, because copper fatigue failure
  - The solution was a complete rewind (following additional findings)



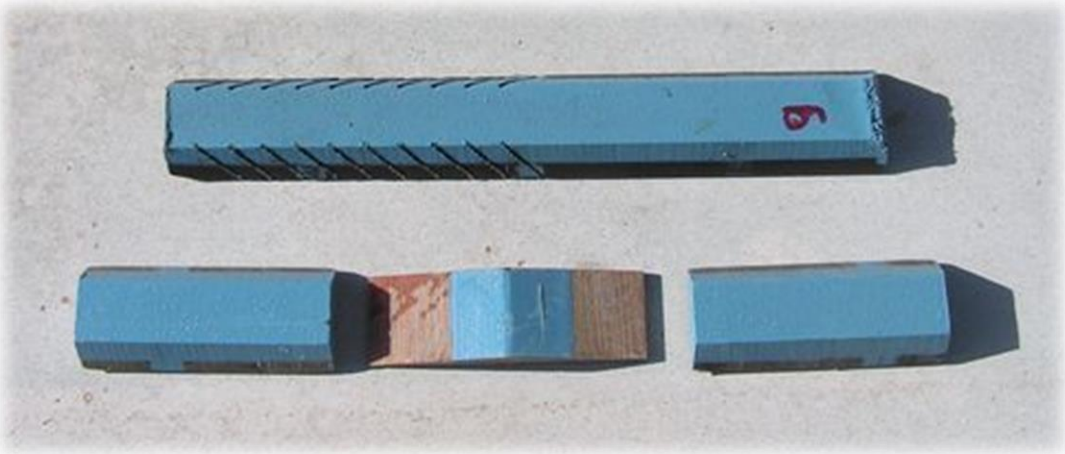


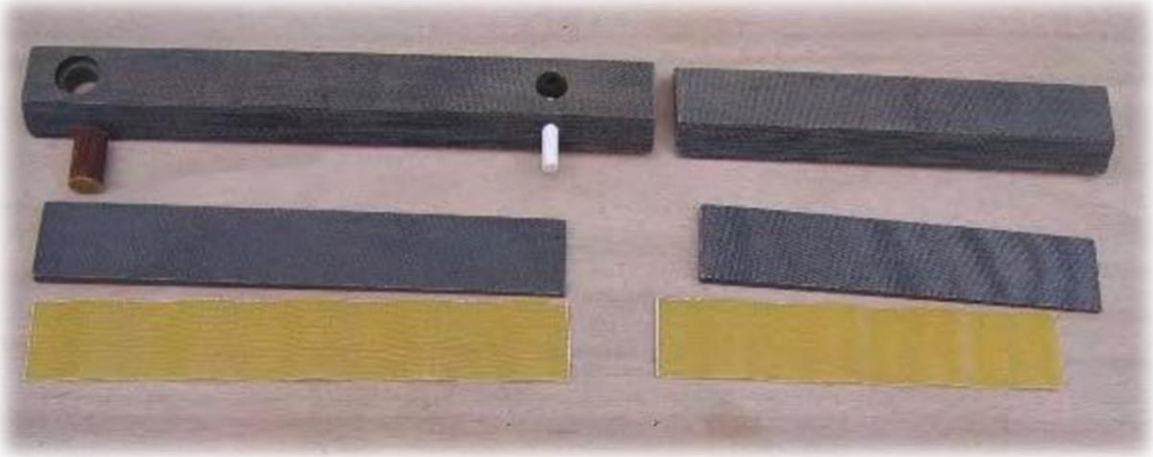
Rotor Issues

- **Rotor rewind summary**
  - During the years, 5 complete and 2 partial rewinds have been performed
  - Most rewinds done in our power plants, with old copper and without high speed tests
  - In other 3 cases, the faulty rotor replaced by spare and repaired in contractor's factory

Stator Issues

- **Loose slot wedges**
  - Most probably related to two-shift operation / vibrations / oil contamination
  - Occurred in all machines, as soon as after 13-14 years or 1400-1500 starts
  - Solution: partial or full replace of Camel Back wedges by Piggy Back (inclined plane) & top ripple springs



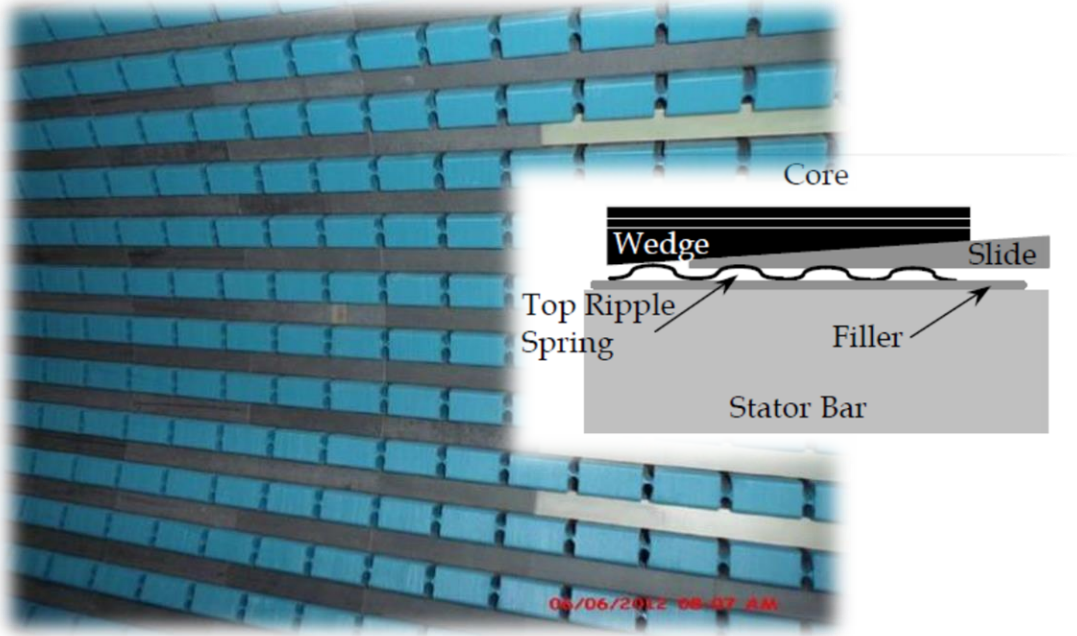


Stator Issues

- **Greasing and loose ties**
  - Greasing results from end-winding loose ties / blocks, oil contamination
  - Found in some generators, for example after 18 years and 3300 starts
  - All loose ties have been removed and replaced, or retighten / repaired

Stator Issues

- **Stator rewedge summary**
  - During the years, full rewedge was done in 6 machines
  - Partial rewedge was performed in other 4 generators
  - Rewedge extent according to wedge tightness test & acceptance criteria



Other Issues

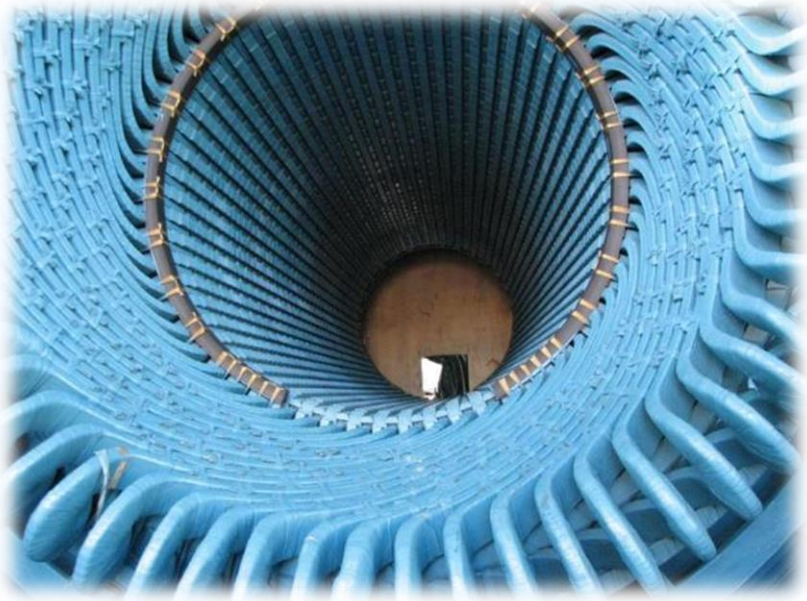
- **Bushing damages**
  - In 2 generators, after 13-17 years or just 1300 starts
- **Increased vibrations**
  - Occurred in 4 machines from various reasons:
  - One case related to thermal sensitivity (closed vents)
  - Another case was a result of misalignment condition
  - In other cases may be difficult to find the root cause
- **Static excitation**
  - Voltage regulators based on solid-state analogue electronic cards, original and still in operation

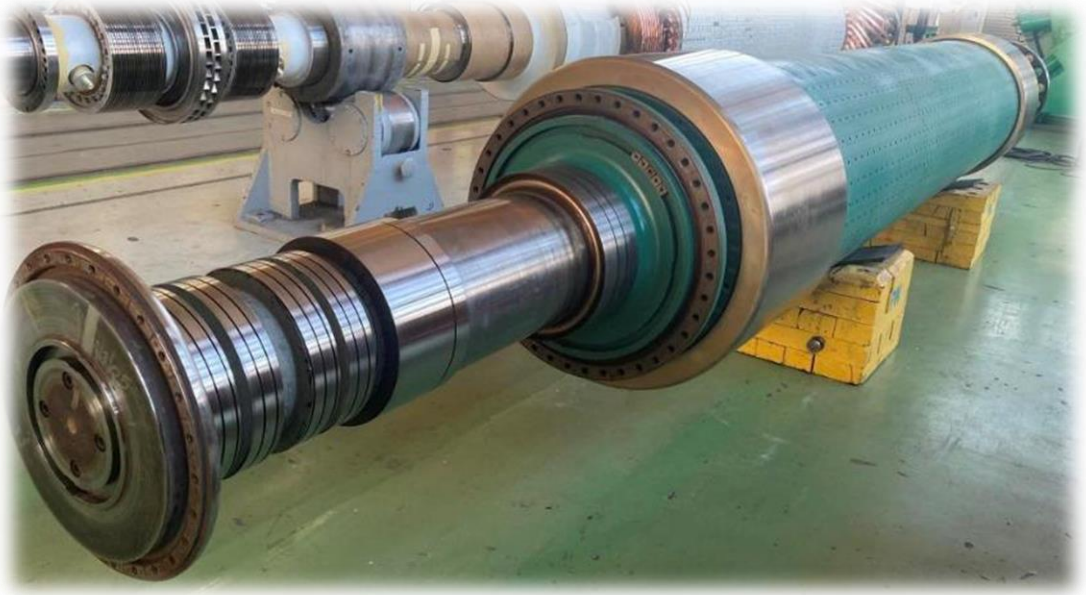
Monitoring & Testing

- Visual / borescope inspection of stator and rotor, electrical tests: insulation resistance, PI
- Offline tan delta and PD up to phase voltage. At major outage also ELCID, wedge tightness, RSO
- Complete rewinds opportunity used to perform NDT metallurgic inspection on forging (TIL 1292)
- Flux probes installed in 9 out of 12 generators: 4 w/o shorts, 3 with 1 short, 2 with 2-4 shorts
- No online stator winding PD monitors installed. No special issues on stator insulation
- In some generators EMI done, without findings

Critical Spare Parts

- **Stator spare parts**
  - 6 top bars and 6 bottom bars (10% of installed) stored, luckily never used
  - A complete set of wedges and ancillary materials stored for emergency
- **Spare rotor**
  - Acquired in 2010, after interchangeability study by OEM. Used 3 times





Conclusions

- 35 years after manufacturing, 25-31 service years and 2700-5400 starts, 9H2 generators are still reliable, mainly as a result of their design simplicity
- The most common failure modes are related to the two-shift operation mode. By EPRI 1008351 cycling regime may increase forced outages up to 5 times
- Most stators (10 out of 12) experienced during the years a partial / full rewedge, performed after an average operation life of 2600 starts or 16 years
- Most rotors (10 out of 12) underwent significant maintenance, a partial / full rewinding or a replacement, after an average 2400 starts or 14 years
- It is expected that a new series of rotor rewinds and stator rewedge will be necessary in the near future, despite the number of starts slightly decreased

Thank you!

reluilie@iec.co.il