Health Monitoring of Rotating Equipment from Torsional Vibration Features

Martin W. Trethewey
Department of Mechanical and Nuclear Engineering
Penn State University

April 13, 2007

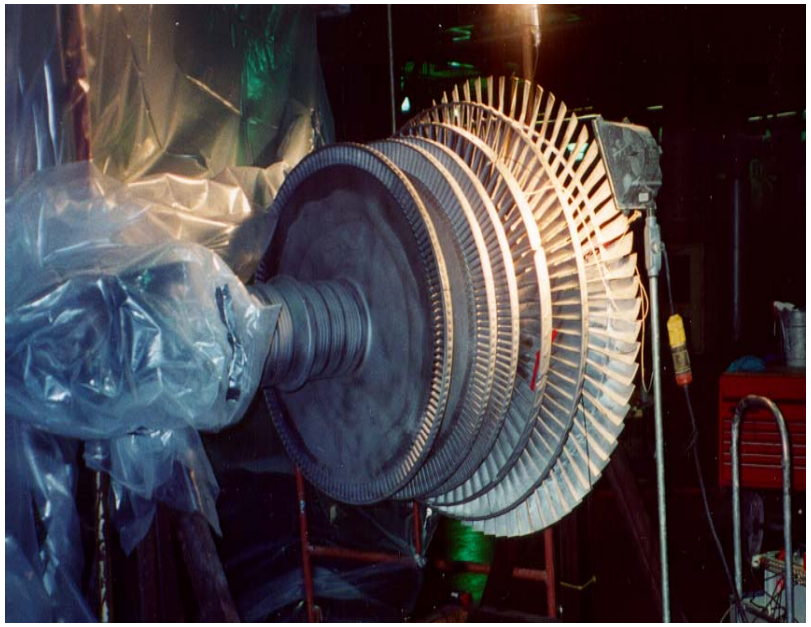
Project Participants

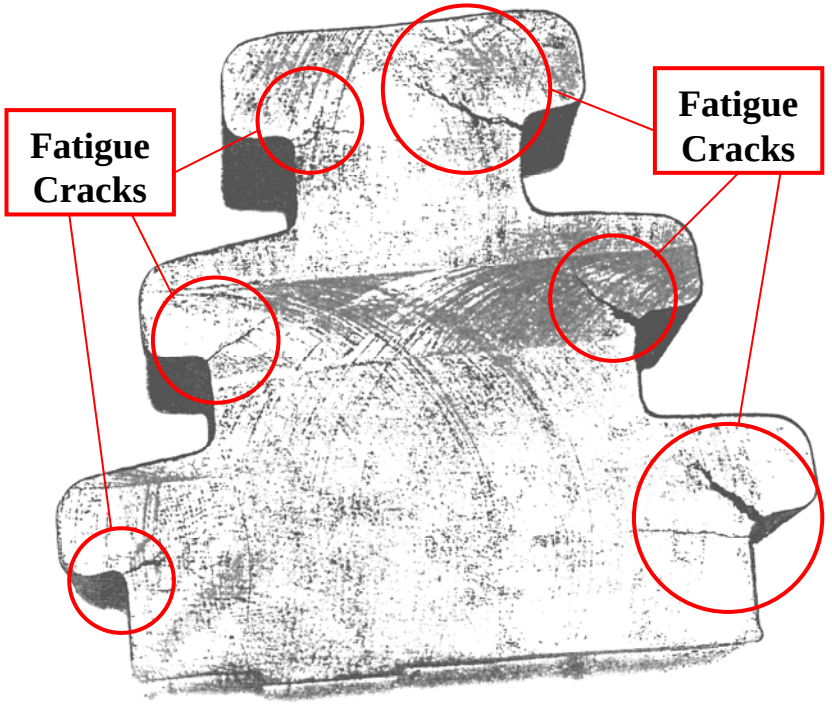
- Penn State University
  - Applied Research Laboratory
  - Mechanical & Nuclear Engineering
  - Engineering Science & Mechanics
- Tennessee Valley Authority
- Electricité de France
- Southern Company
- Dominion
- Framatome ANP - Jeumont
- EPRI

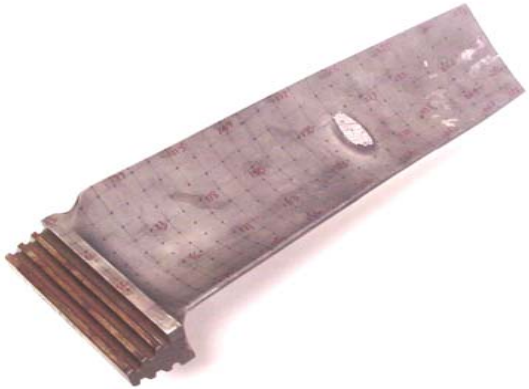
Electric Power Generation Mechanical Equipment

- Subject to:
  - High loads
  - Thermal gradients
  - High operating hours
  - Corrosion
  - Radiation
- Results
  - Fatigue cracks

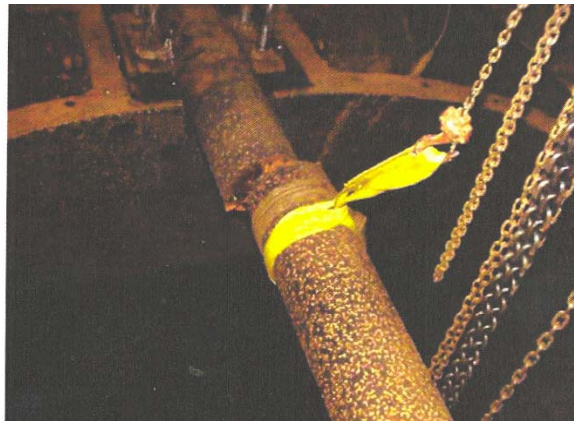
Fossil
Boiler Feed Pump Blades







Hydro
Turbine Driveshaft



Nuclear
BWR Recirculation Pumps

- NRC Information Note 2005-08
  - April 2005

- Many Byron Jackson (now Flowserve) RRP shafts have been inspected
  - ALL have some thermal cracking at thermal barrier
  - Axial cracks
  - Generally benign

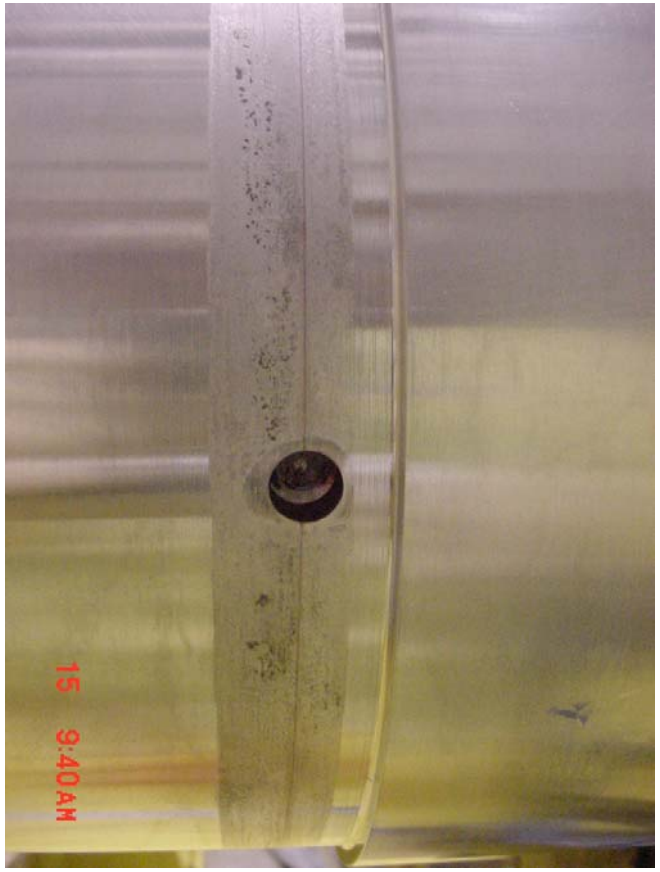
- Dangerous Circumferential Cracks
  - Axial thermal cracks change direction under mechanical loading
  - Fast growing
  - Can cause catastrophic shaft failure

- General Electric recommends ALL pumps with 80,000 hours service be inspected and monitored for cracks

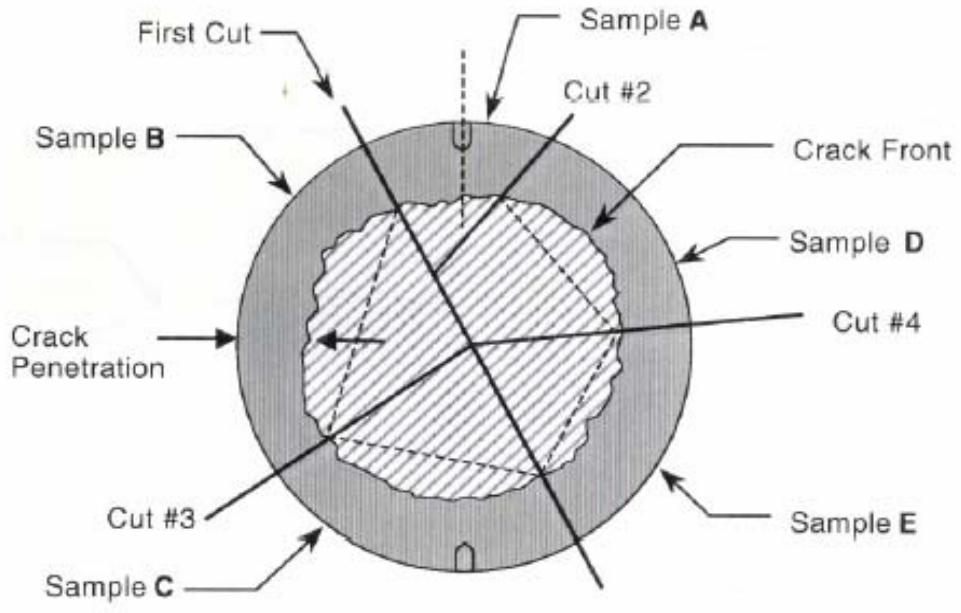
TVA Nuclear
Shaft Crack History

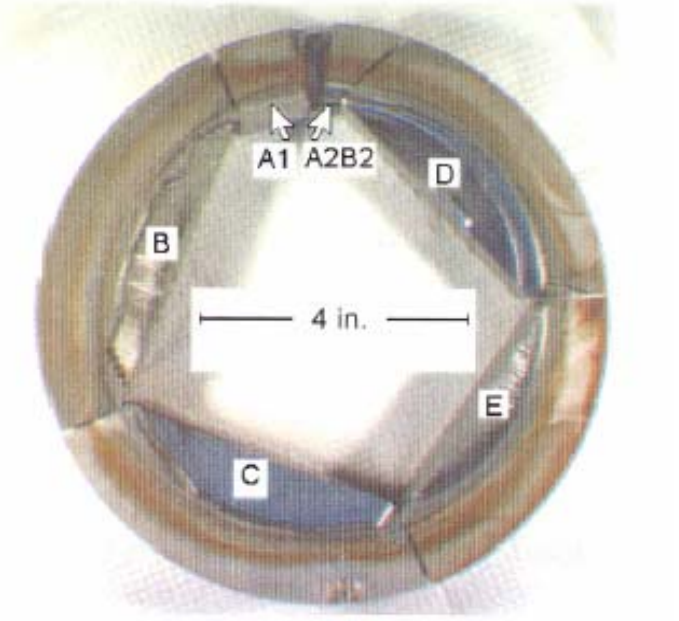
- Browns Ferry - Reactor Feed Pump
  - October 1979
- Browns Ferry - Recirculation Pump
  - January 1984
- Watts Barr - Main Feed Pump
  - April 1997
  - June 1997
- Sequoyah - Centrifugal Charging Pump
  - July 1981
  - January 1994
  - April 1999
- Sequoyah - Reactor Coolant Pump
  - October 2000
  - April 2002
  - Spring 2005

TVA Sequoyah RCP 2-1
June 2002



Post Mortem


First Cut
Sample A
Cut #2
Sample B
Crack Front
Sample D
Cut #4
Crack
Penetration
Cut #3
Sample E
Sample C


A1
A2B2
D
B
4 in.
E
C

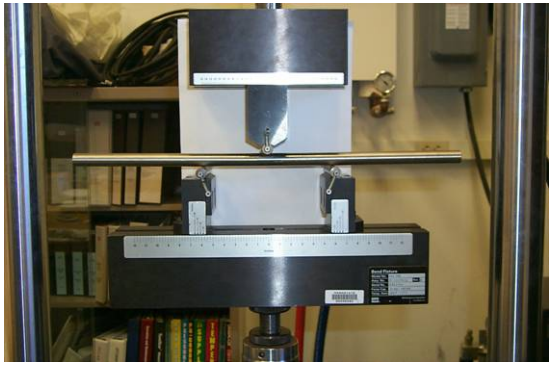
TVA Sequoyah RCP 1-4 2000

Torsional Monitoring

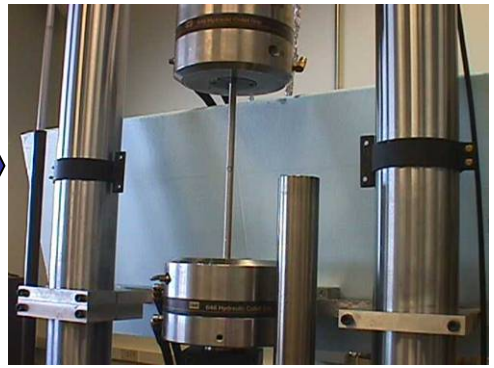
- As a crack propagates
  - Stiffness decreases
  - Decrease in torsional natural frequency
- Torsional domain less susceptible to
  - Seal rubs
  - Changes in film bearing stiffness
  - Thermal growth
  - Misalignment
- If a torsional natural frequency change is observed
  - A change in the line shaft dynamics occurred

Laboratory Feasibility Evaluation

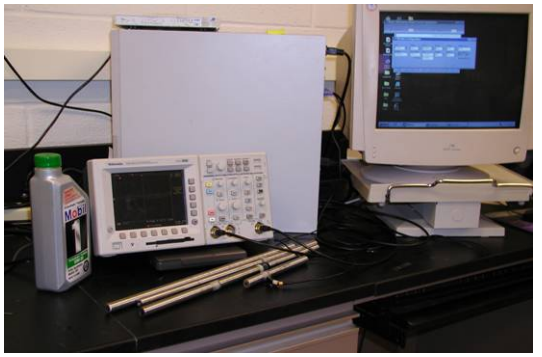
Fatigue Cycling



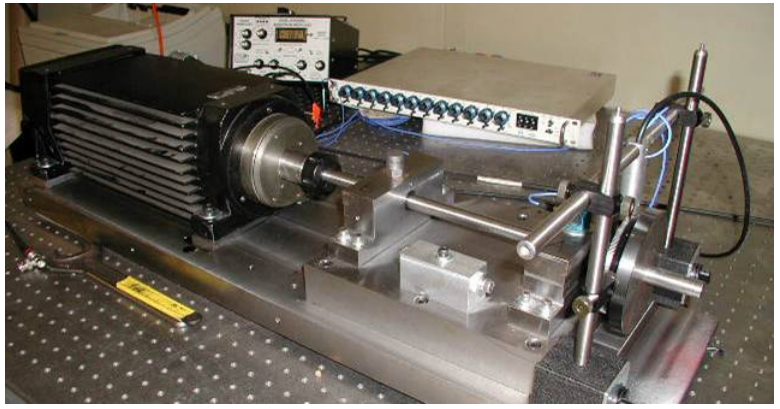
Torsional Stiffness



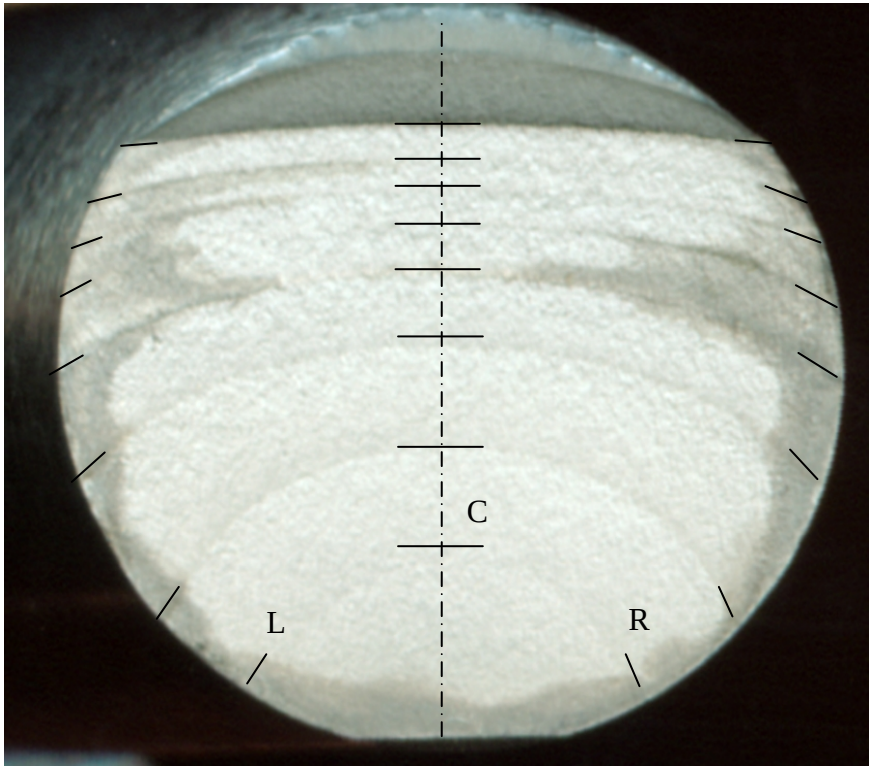
NDE Crack Inspection

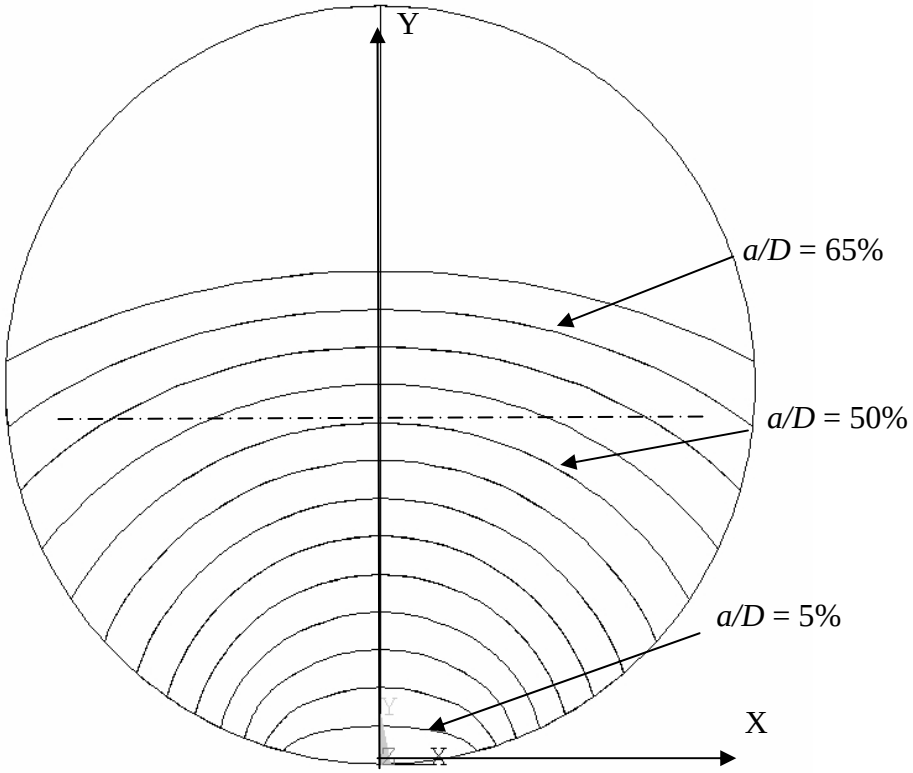


Torsional Vibration Signature Analysis

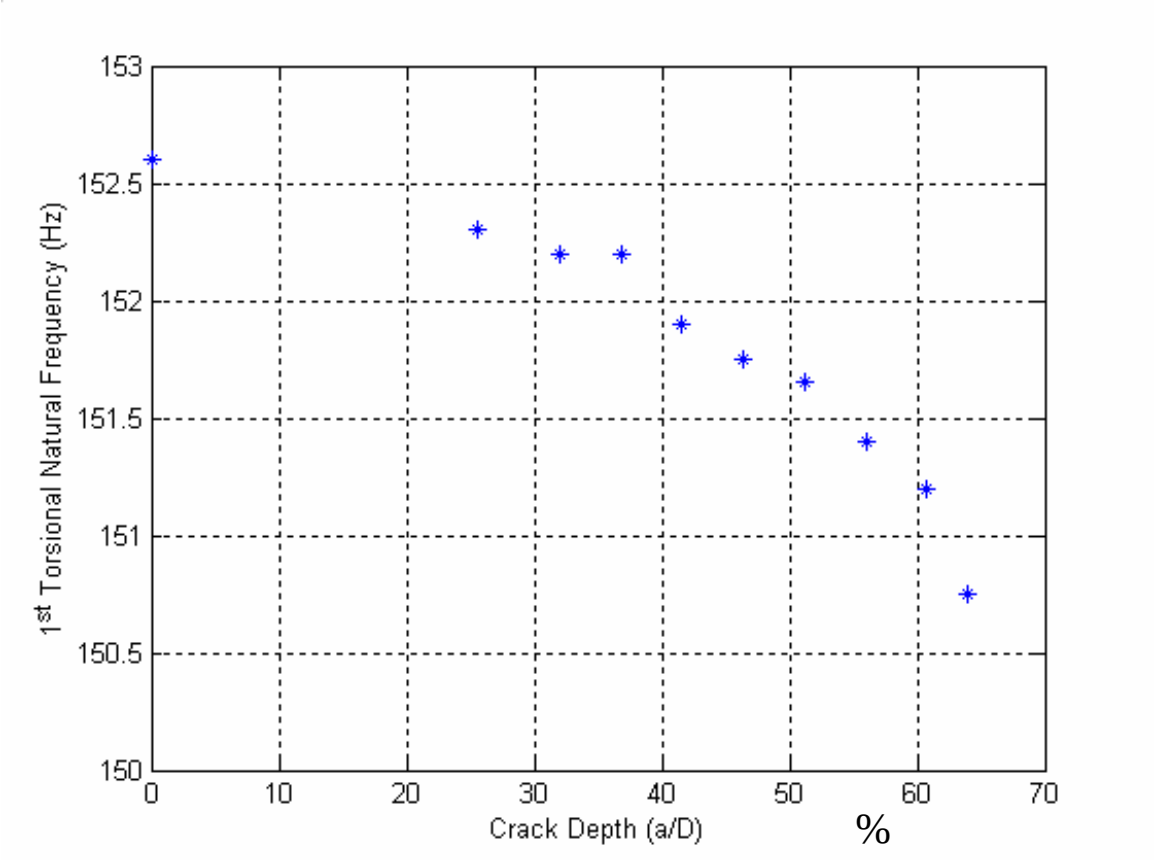


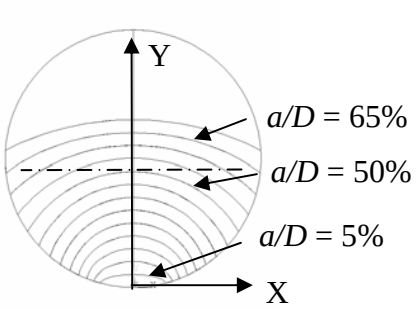
Post Mortem Crack Inspection





Torsional Natural Frequency versus Fatigue Crack Depth

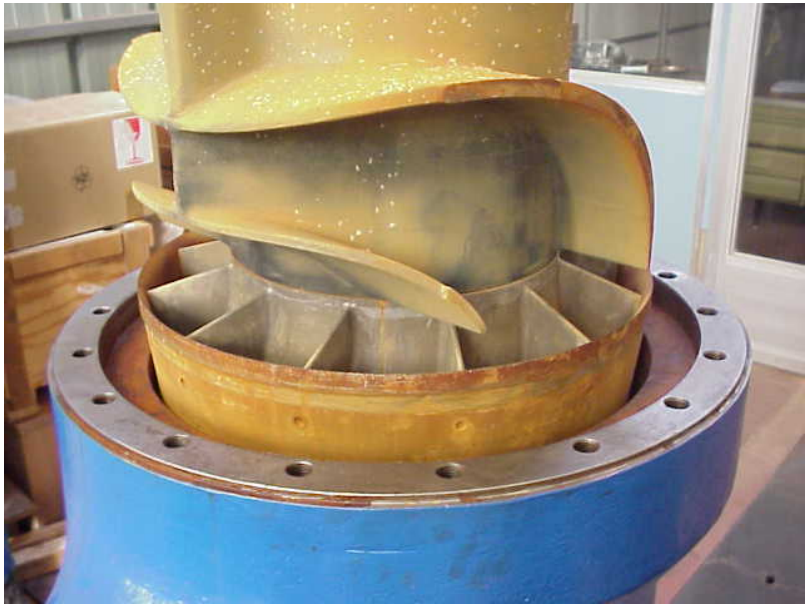




Objective 2
41% Scale Seeded Fault
RCP Tests

AREVA
41% Reduced Scale RCP Loop

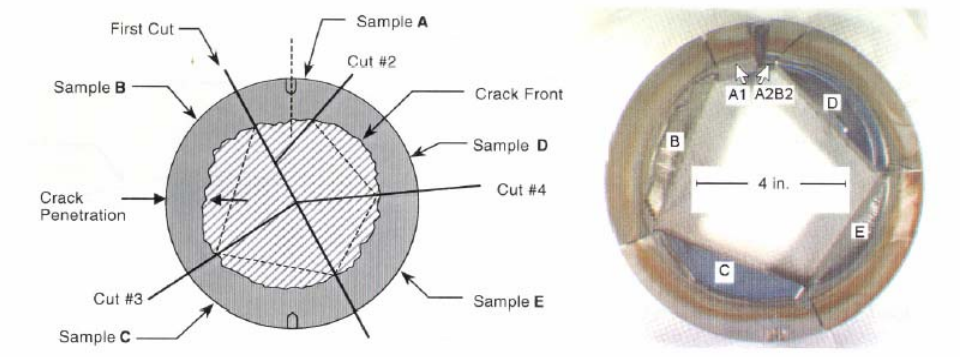
Reduced Scale 93A RCP

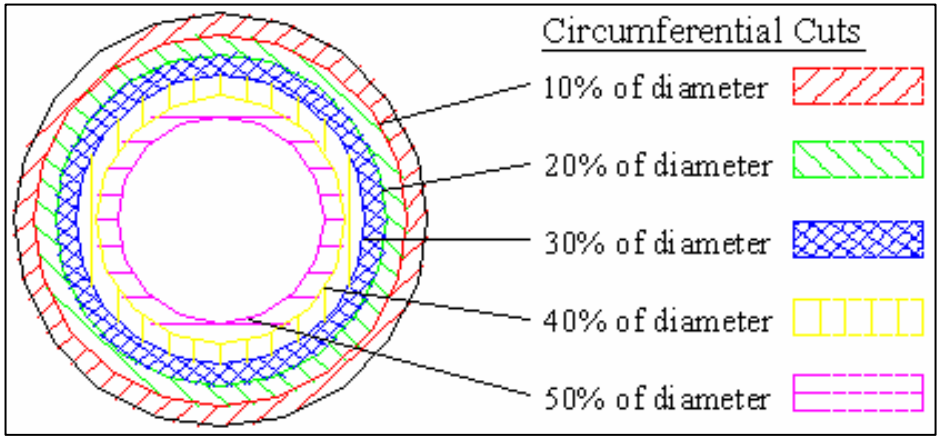


Circumferential Cut Testing

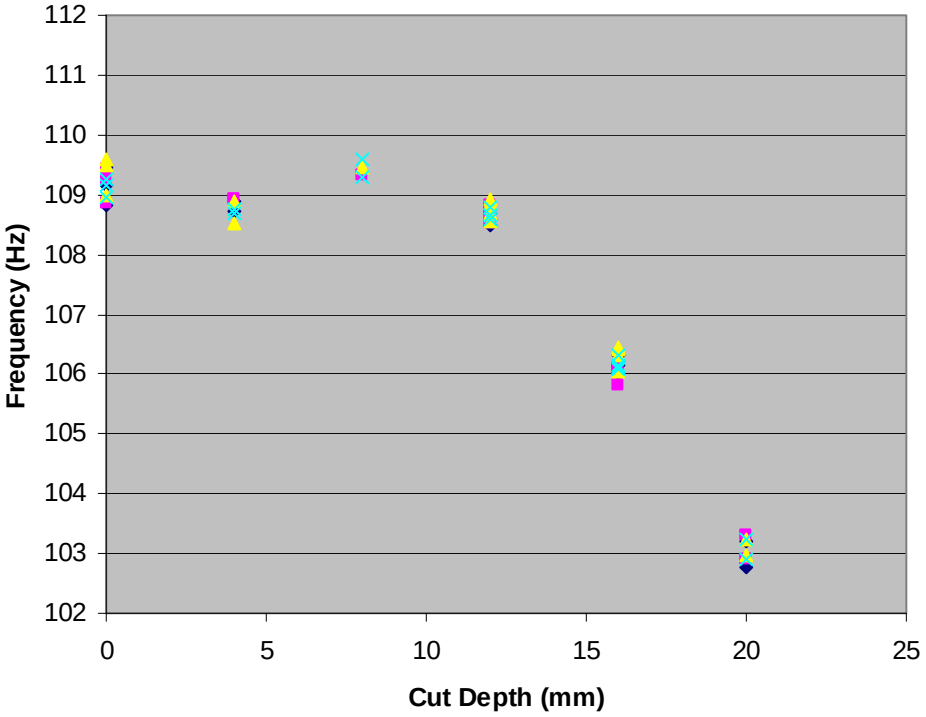
- 5 sequential cuts
  - 4 mm (10% of the diameter)
  - 8 mm (20% of the diameter)
  - 12 mm (30% of the diameter)
  - 16 mm (40% of the diameter)
  - 20 mm (50% of the diameter)

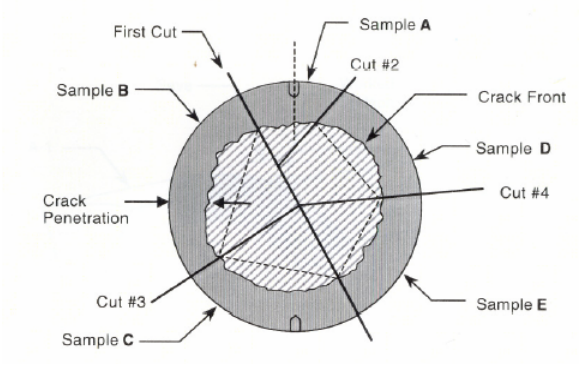
2002 TVA Sequoyah RCP 2-1

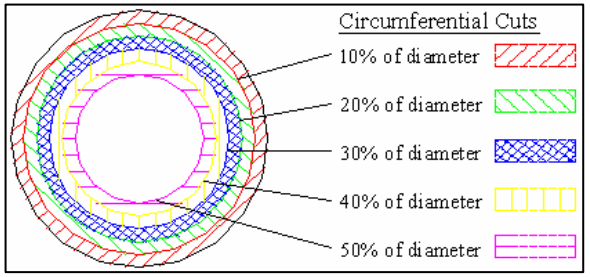




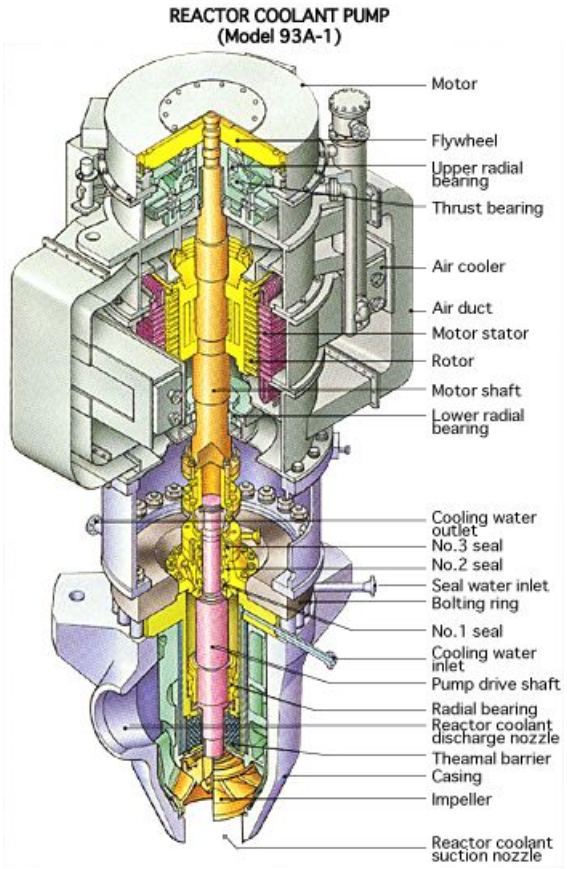
Circumferential Cuts
1st Torsional Frequency





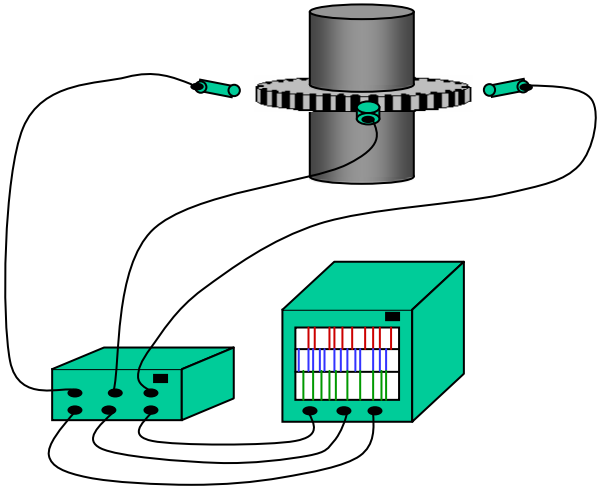


PWR Reactor Coolant Pump



Pump Description	Vertical shaft Single stage Suction diffuser type Limited leakage system
Flow	20,200 m3/h
Net Pump Head	80 - 90 m
Nominal Operating Temperature	About 290 degree C
Speed	1,190 RPM
Nominal Motor Power	4,480 kW 6,000 HP

93A RCP Torsional Hardware



Mechanical Installation

Torsional Vibration Feature Trending

- Started after November 2004 refueling outage
- Acquired on two pumps
- 20 minutes data snapshots
- Acquired twice a day
  - At different times throughout the day

Project Status Based on TVA Data Assessment

- Crack sensitive torsional features observable
- Provides critical design and installation experience
  - Will guide changes to improve performance
- Acquired torsional data sufficient for
  - FEM Refinement
  - Trending
  - Variation assessment

Project Status

- **Potential –** a technology capable of detecting and monitoring shaft crack growth
  - Early detection of cracks
  - Significantly superior to existing technology
  - Readily adaptable to other pumps and rotating equipment

Acknowledgements

This work was supported by the Electric Power Research Institute (EPRI Contract EP-P9801/C4961).

The content of the information does not necessarily reflect the position or policy of the EPRI, and no official endorsement should be inferred.