Developmental Test Results

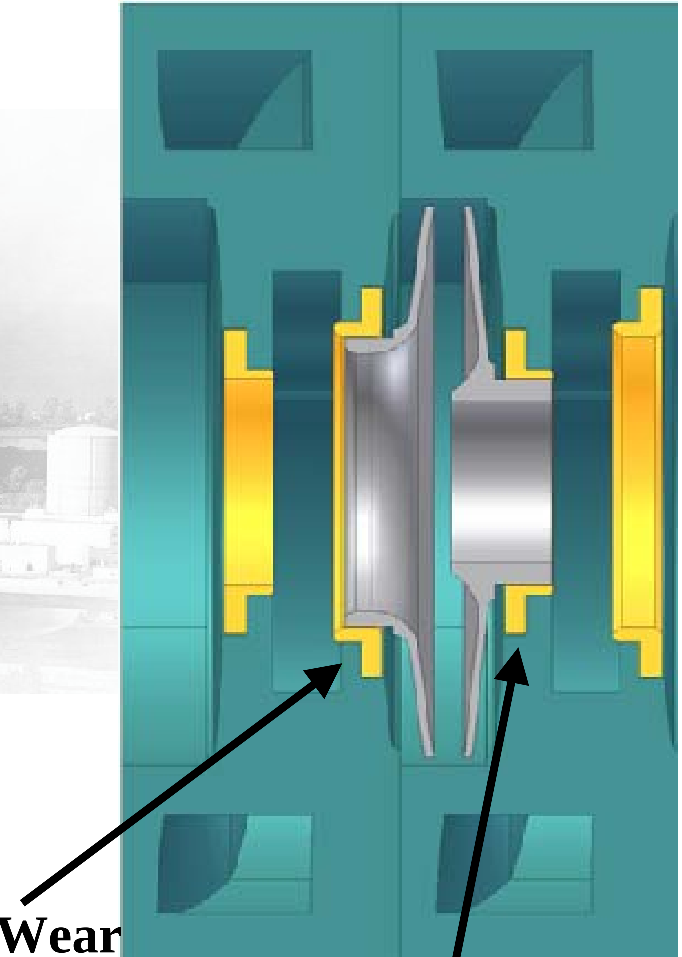
- The original test conditions were unrealistic – LBLOCA debris for SBLOCA operating conditions
- Several key assumptions proved invalid
  - Soft, larger debris became lodged in bearing pockets and orifices
  - Velocities in volute were not sufficient to keep finer strainers clear
  - Wear was greater than anticipated, particularly for soft components
  - Close clearances are subject to plugging

Revised Design Concept

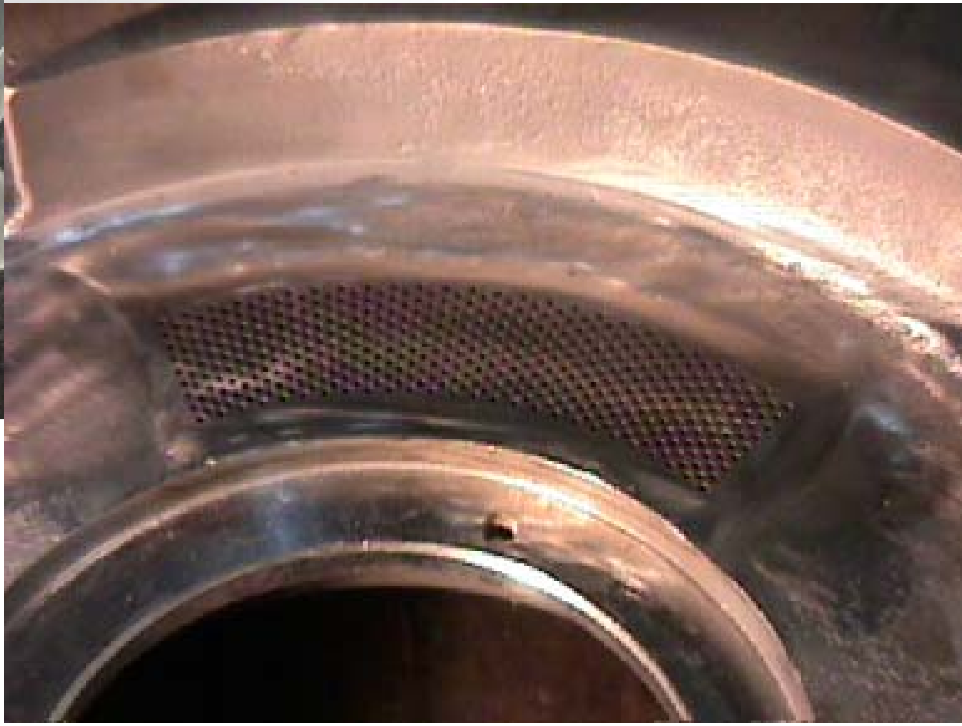
- Three primary load carrying components: hydrostatic bearing, wear rings, and central volute bushing
- Rotordynamic analyses show several acceptable conditions
  - Functional hydrostatic bearing and bushing
  - Functional hydrostatic bearing and wear rings
  - Functional wear rings and bushing
- Use defense-in-depth approach and address all three components to ensure they function under debris loading

Revised Design Concept
(Continued)

- Use 50 mil strainer to protect hydrostatic bearing orifices
- Locate strainer on discharge side of impeller, close to wear ring to reduce concentration and size of debris reaching hydrostatic bearing
  - Wear ring acts as a strainer
  - Centrifugal effect on heavier debris maximized
  - Discharge side of volute maintains high velocity for all pump flows
  - Standard approach used by Pump Guinard for French PWRs



Volute Modifications



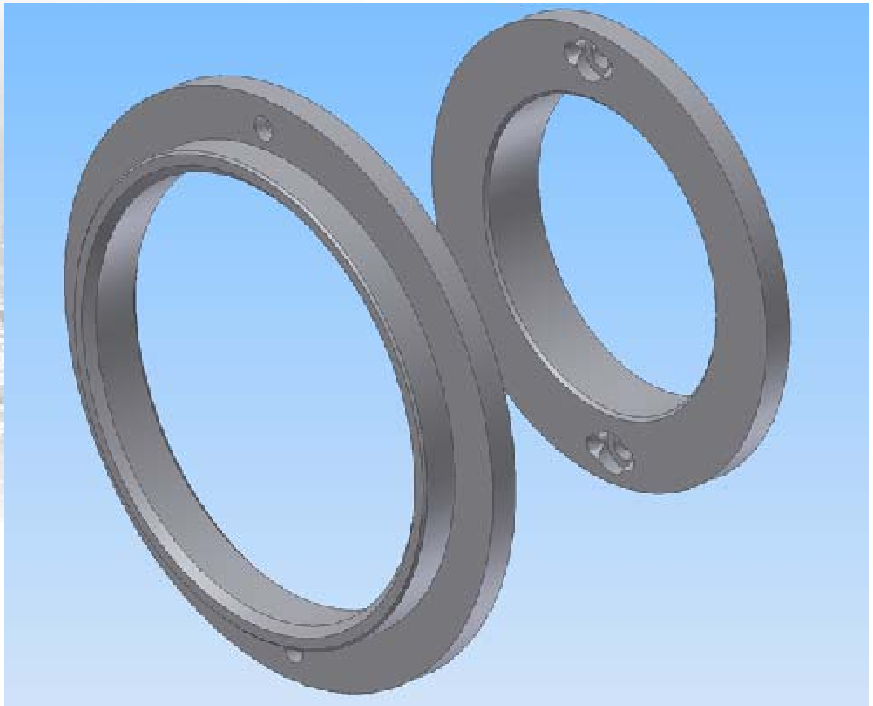
Revised Design Concept
(Continued)

- Modify hydrostatic bearing to improve debris tolerance
  - Add "escape" grooves to pocket
  - Change rectangular pocket to "8" pocket based on Pump Guinard design

"8" Pocket Hydrostatic Bearing

Revised Design Concept
(Continued)

- Hardface all critical wear surfaces: wear rings, bushing and shaft sleeve, hydrostatic bearing and sleeve



Suction and Discharge Wear Rings

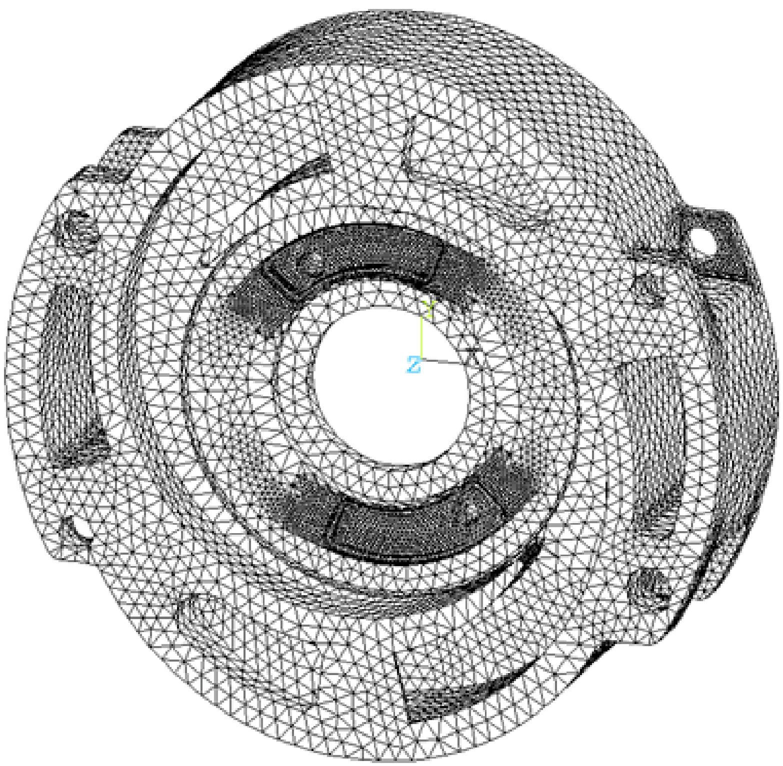
Analysis and Qualification Testing

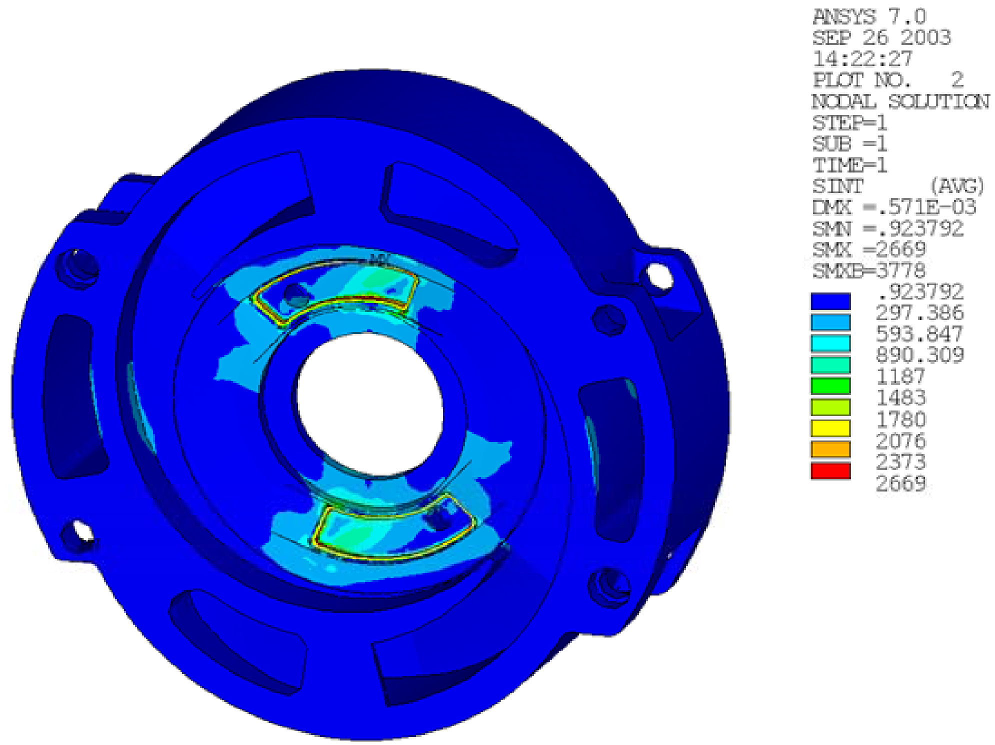
Bob Coward
MPR Associates

Modification Design Analyses

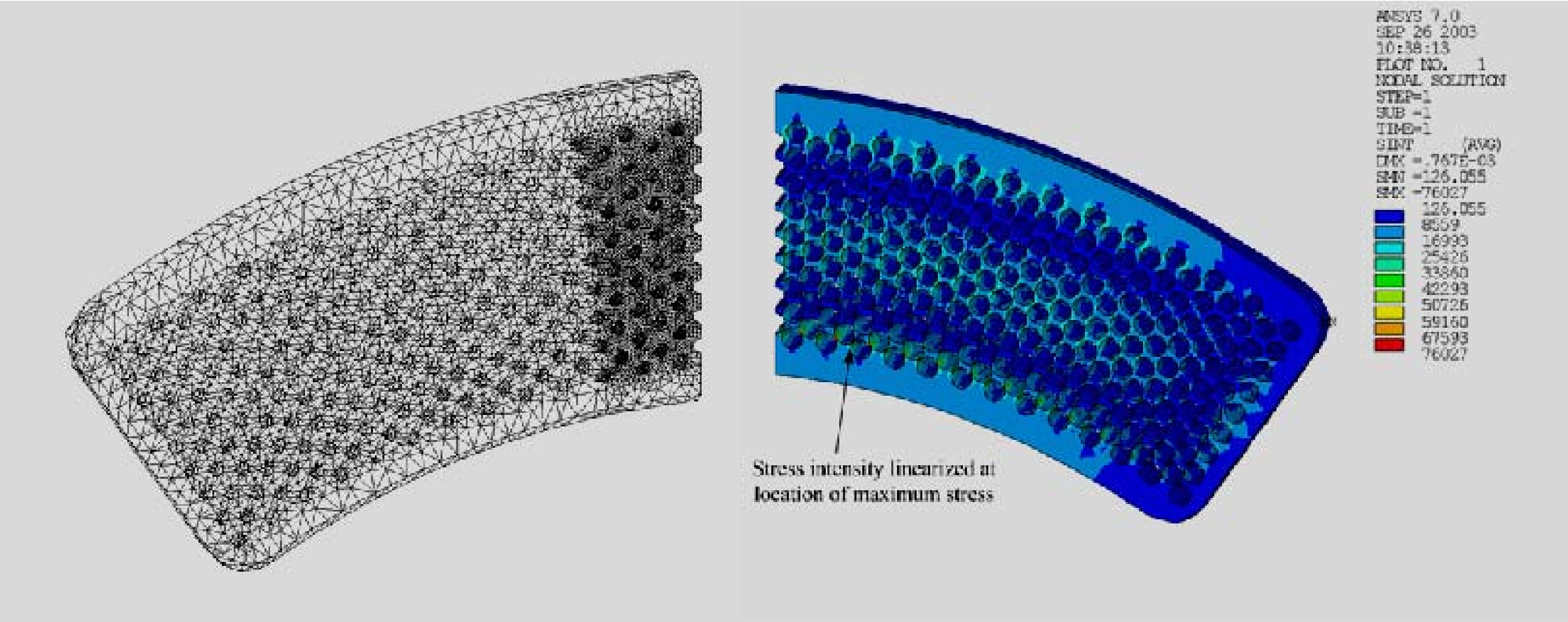
- Volute stress analysis
- Strainer stress analysis
- Hydrostatic bearing load carrying capability and stiffness
- Failure modes and effects analysis
- Hardfaced parts equivalency evaluations

Volute Finite Element Model

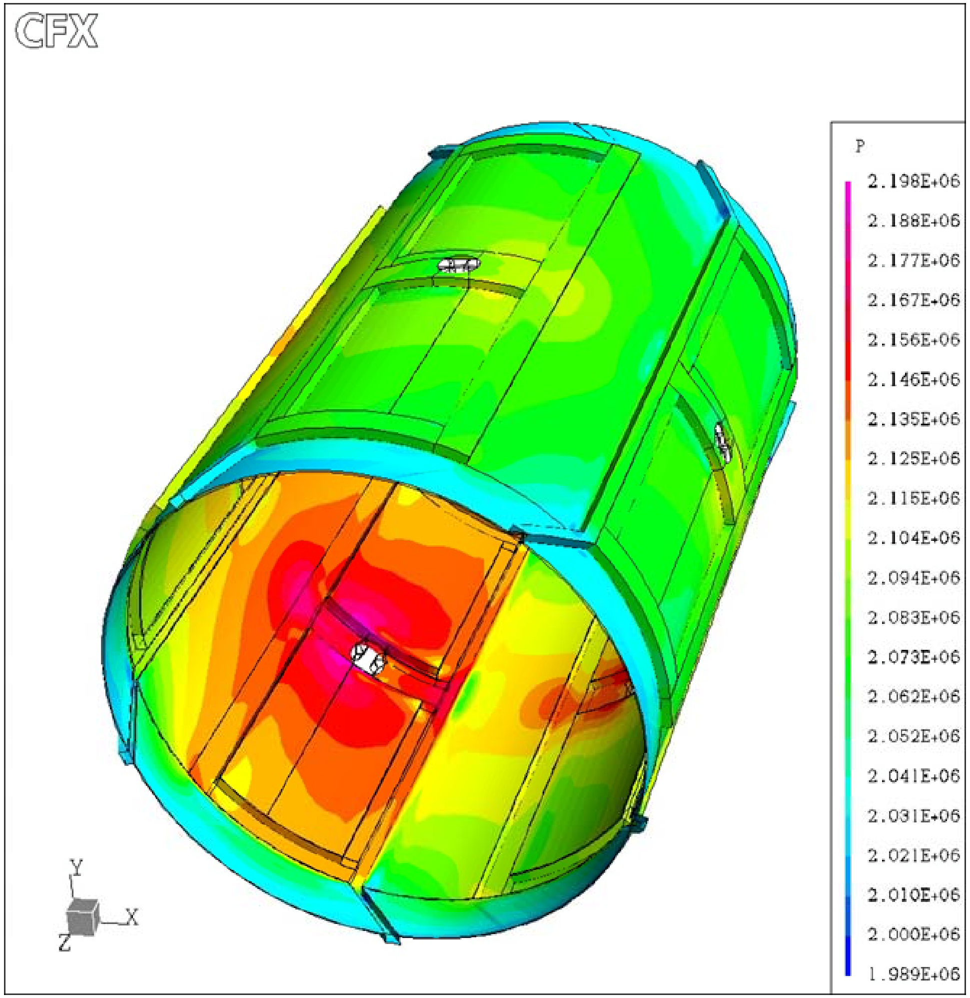




Strainer Finite Element Analysis Stress



Hydrostatic Bearing Analysis



Failure Mode and Effects Analysis

- Considered all modifications to pump
- Evaluated potential failure modes for modification design
- Concluded no new failure modes are introduced

Qualification Testing Overview

- Use separate effects testing to evaluate pump internal components individually
  - Avoids contamination concerns
  - Addresses parts availability concerns
  - More flexible than full pump test
- Key elements of program included:
  - Fixture designs match critical characteristics of HPI pump
  - Full scale components
  - Debris characterization based on Davis-Besse containment
  - All testing in accordance with MPR’s Quality Assurance Program

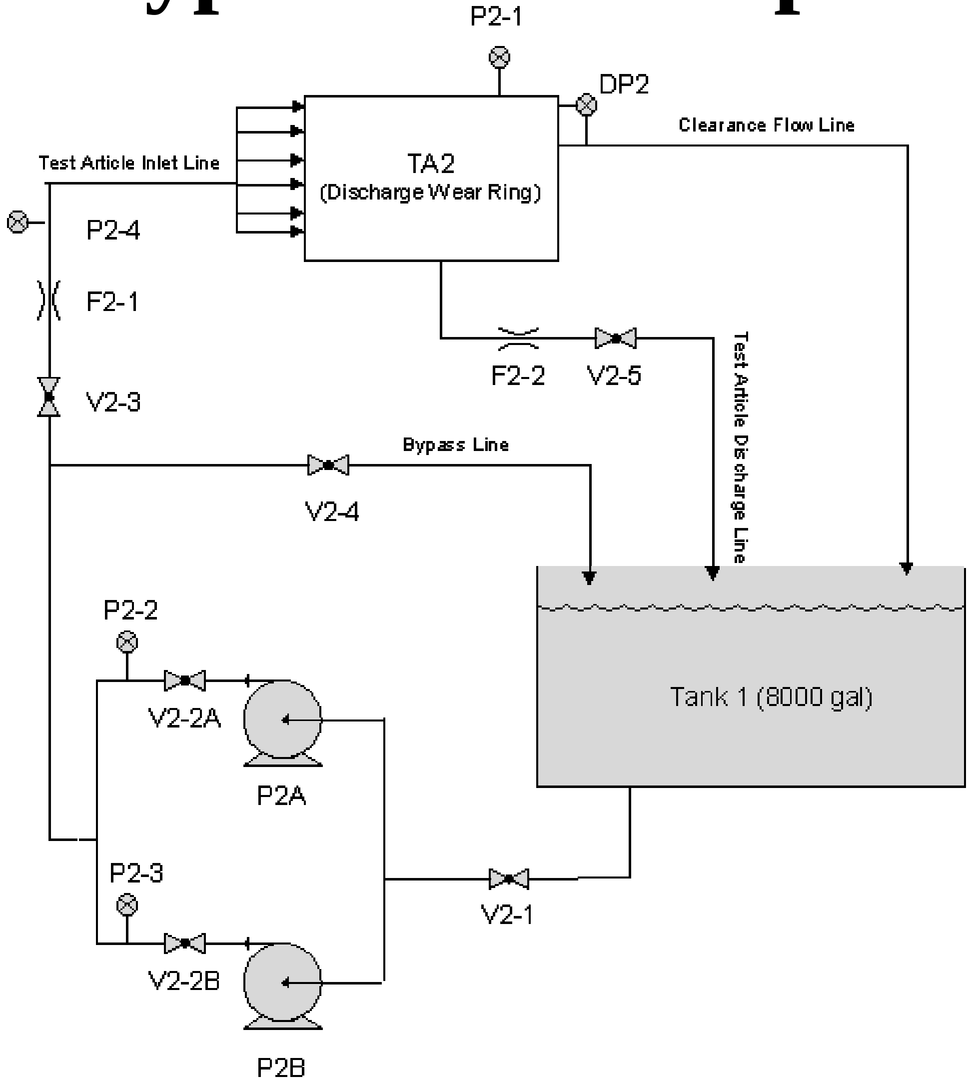
Qualification Testing Configuration

- Five test loops
  - –Loop 1 – Suction Wear Ring
  - –Loop 2 – Discharge Wear Ring
  - –Loop 3 – Hydrostatic Bearing
  - –Loop 4 – Central Volute Bushing
  - –Loop 5 – Hydrostatic Bearing Supply Strainer
- 8000 gallon supply tank simulating sump (including debris) supplied Loops 1, 2, 4, 5
- Loop 3 (hydrostatic bearing) supplied through Loop 5 strainer

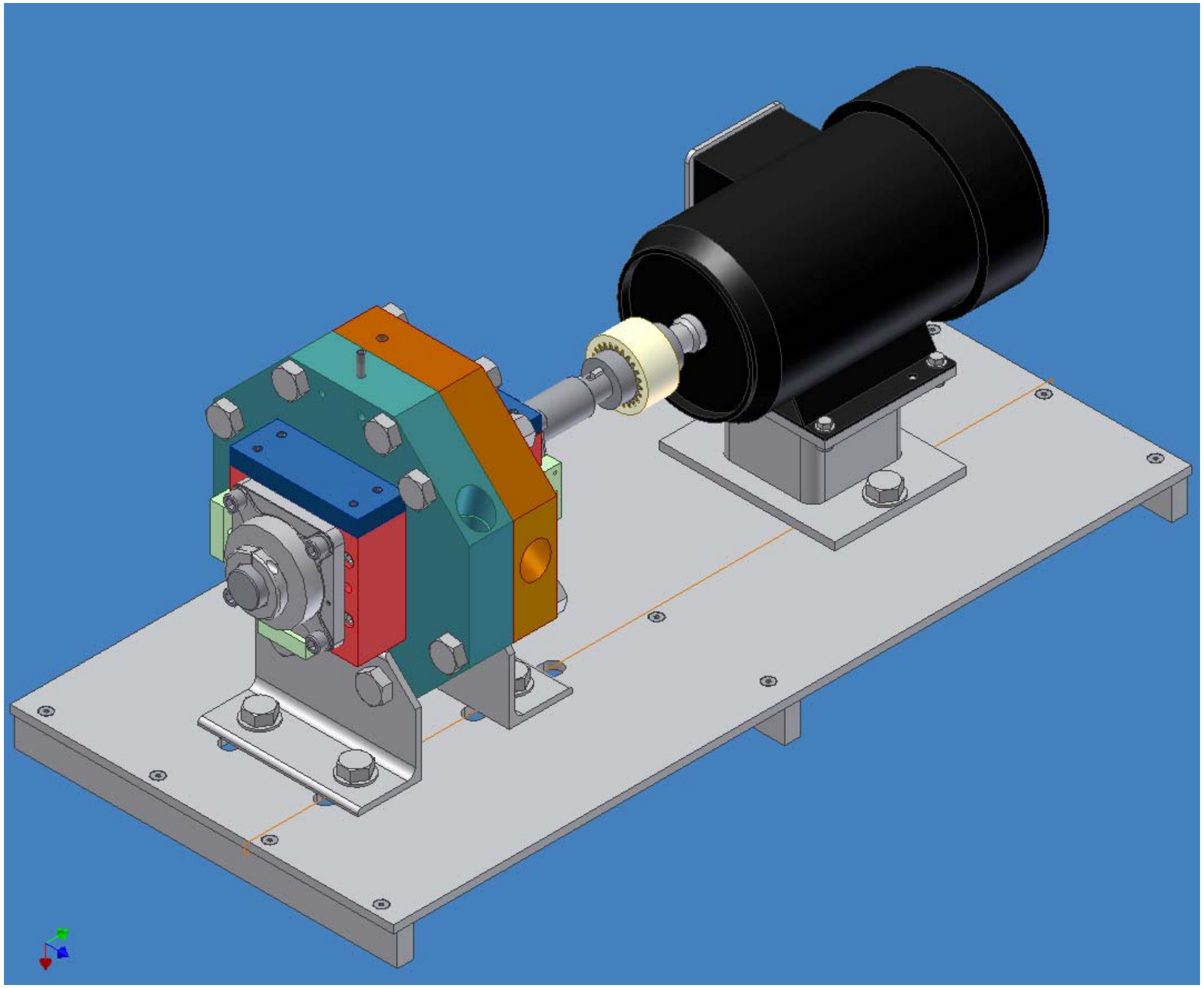
Qualification Testing Objectives

Loop	Objectives
Suction Wear Ring & Discharge Wear Ring	Measure Clearance Increase and Measure Flow Rates
Hydrostatic Bearing	Measure Clearance Increase and Confirm Adequate Flow
Central Volute Bushing	Measure Clearance Increase and Measure Flow Rates
Hydrostatic Bearing Supply Strainer	Confirm Adequate Flow

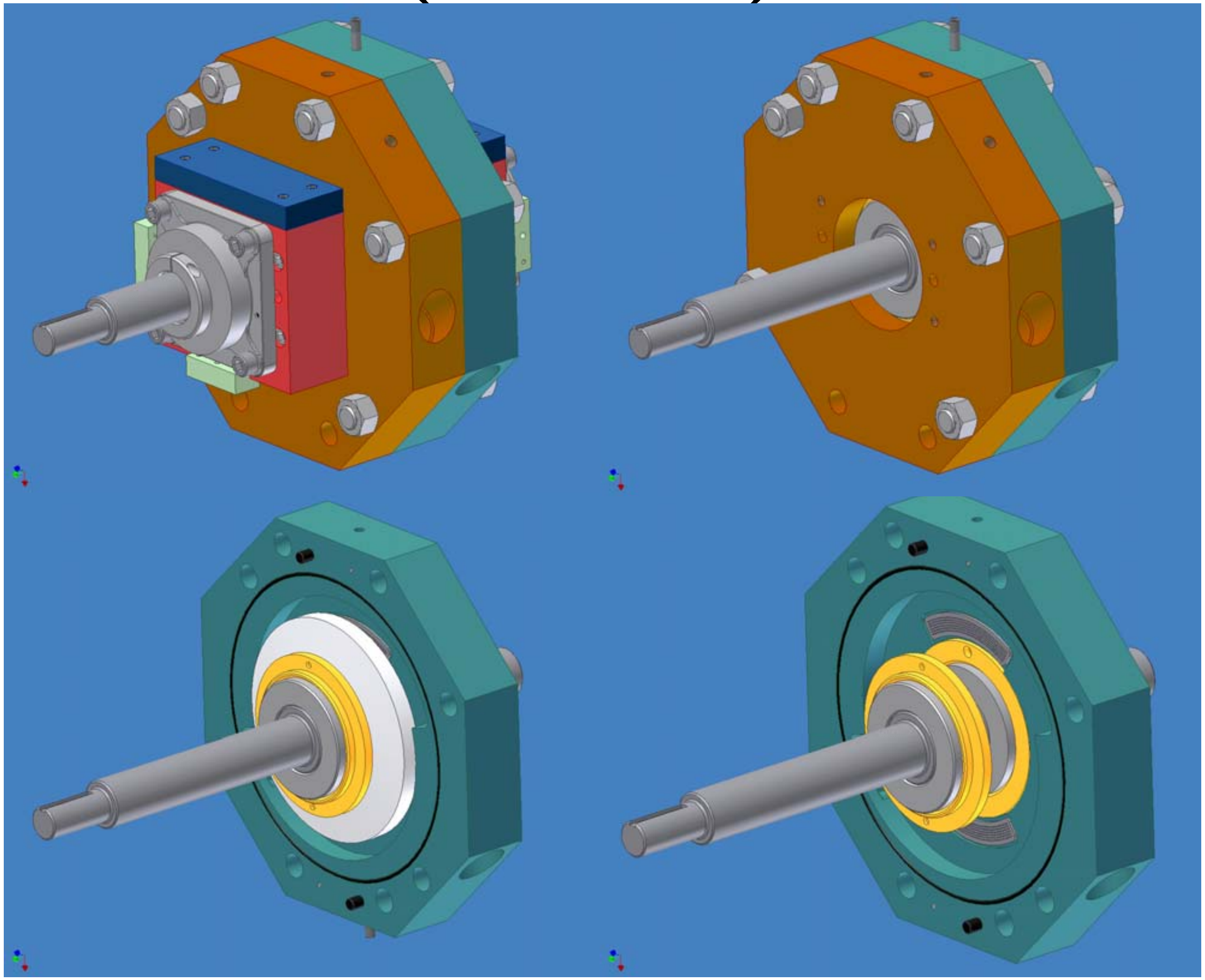
Typical Test Loop



Suction Wear Ring Test Fixture



Suction Wear Ring Test Fixture
(Continued)

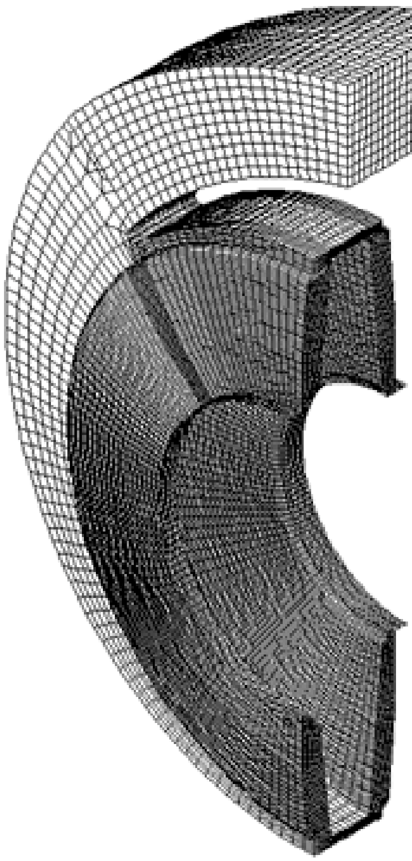


FirstEnergy

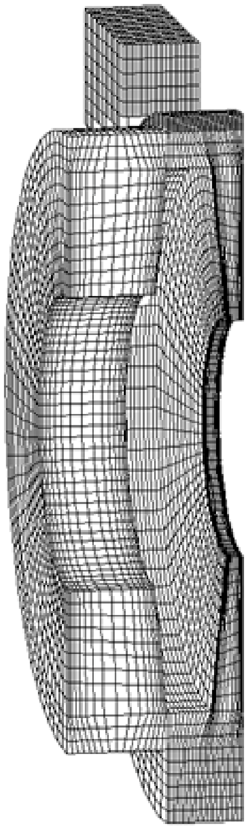
Test Fixture Equivalency Evaluation

- Design Configuration
  - Verify test fixture dimensions and materials match the HPI pump internals
- Flow Fields
  - Hydraulic and Computational Fluid Dynamics (CFD) analysis of test fixtures compared to HPI pump
- Operating Conditions
  - Test flow rates and pressures consistent with HPI pump functions
- Debris Characteristics
  - Use types, sizes and quantities of the debris expected in LOCA

CFD Modeling HPI and Loop 5 Pumps



HPI Pump



Loop 5 Pump