NRC FORM 658
(9-1999)

U.S. NUCLEAR REGULATORY COMMISSION

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DATE OF MEETING
10/21/2003

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Docket Number(s)	50-346
Plant/Facility Name	Davis-Besse
TAC Number(s) (if available)	
Reference Meeting Notice	2003-0761
Purpose of Meeting (copy from meeting notice)	Discuss the modification of the high pressure injection pumps.

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
Jon Hopkins	Senior Project Manager

OFFICE
NRR

DIVISION
DLPM

BRANCH
LPD3

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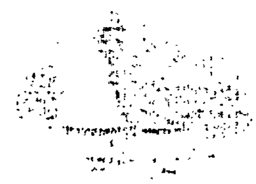

Modification of High Pressure Injection Pumps

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Agenda

- Opening Remarks.. Gary Leidich
- Modification Design..................................... Bob Schrauder
- Analysis and Qualification Testing ....Bob Coward, MPR
- Conclusion...Gary Leidich

Gary Leidich
President and Chief Nuclear Officer - FENOC

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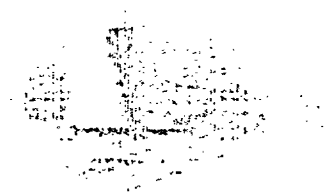
Opening Remarks



Gary Leidich

President and Chief Nuclear Officer - FENOC

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Desired Outcome

- NRC and the public gain confidence that pump modifications and associated testing and analysis ensure the HPI pumps will perform their required safety functions under all design conditions

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Overview

- Background
  - Implemented Building Block approach in 2002 that included assuring the health of plant systems
  - System Health Assurance identified the High Pressure Injection Pumps as an original design issue since fine particles from the Containment Emergency Sump could potentially damage the pumps during the loss-of-coolant accident (LOCA) recirculation mode
- Today
  - Present how these findings were resolved and provide assurance the HPI Pumps are capable of performing their design function

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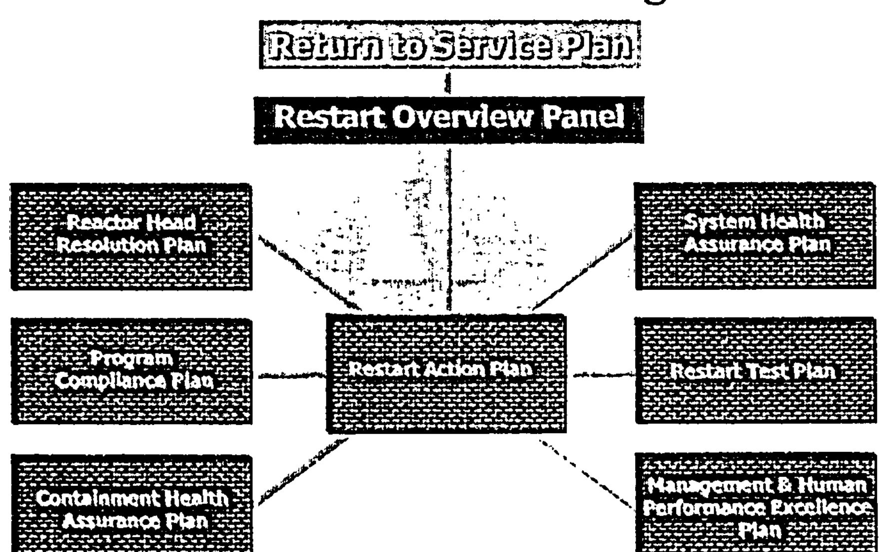
Davis-Besse Restart Building Blocks



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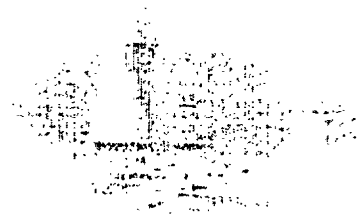
Modification Design



Bob Schrauder

Director -Support Services

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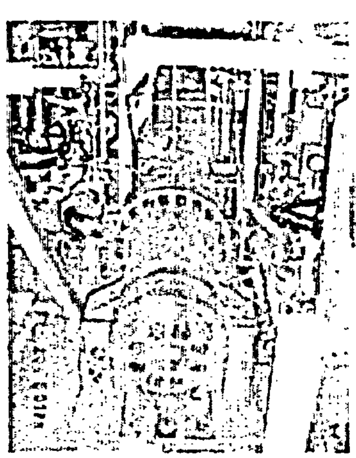
High Pressure Injection Pumps



- Manufacturer
  - Babcock and Wilcox Canada
- Type
  - Horizontal, eleven stage centrifugal pumps
  - 600 HP electric motors
  - Hydrostatic bearing
- Design Pressure/Temperature
  - 2000 psig/ 300°F
- Design/Manufacture Code
  - ASME Pump & Valve Code, Class II, November 1968
- Surveillance Test/Inservice Testing
  - ASME Operation and Maintenance Code (1995 Edition with 1996 Addenda)
- This design is unique to Davis-Besse in domestic nuclear industry

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HPI Pump Operational Environment

- Borated Water Storage Tank Operation
  - –Surveillance Testing
  - –Initial Post-LOCA mode
- Sump Recirculation Operation
  - –In post-LOCA recirculation mode operation, HPI pump suction is from Containment Emergency Sump through LPI pumps
  - –Sump may contain debris from LOCA blowdown and containment spray actuation
  - –HPI Pumps must be capable of operating with debris in the pump flow

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HPI Pump Original Design Issues

- System Health Assurance identified design issues
  - –Hydrostatic bearing plugging
    - –Bearing orifices are smaller than emergency sump strainer and could become plugged
    - –Bearing pocket clearances are smaller than sump strainer
  - –Close clearance wear
    - –Preliminary rotordynamics analyses suggested increases in clearances due to wear by debris could lead to operation at critical speeds
    - –Increased clearances will degrade pump hydraulic performance
  - –Supply path to cyclone separator (seal water) could be smaller than sump strainer and may become plugged

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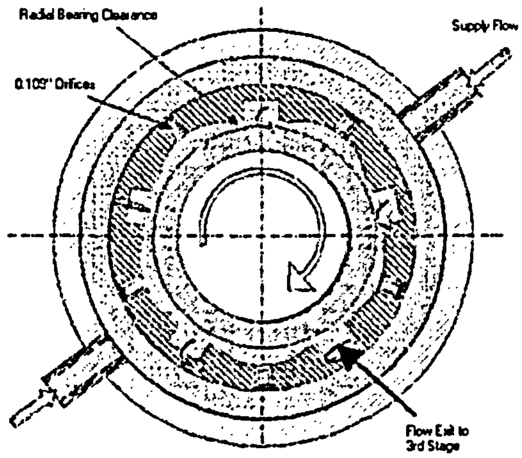
Original Hydrostatic Bearing

- Orifices in supply to hydrostatic bearing pockets are 0.109 inch diameter
- New containment emergency sump strainer has 0.188 inch diameter openings
- Orifices may plug with debris that passed through sump strainer, degrading bearing performance



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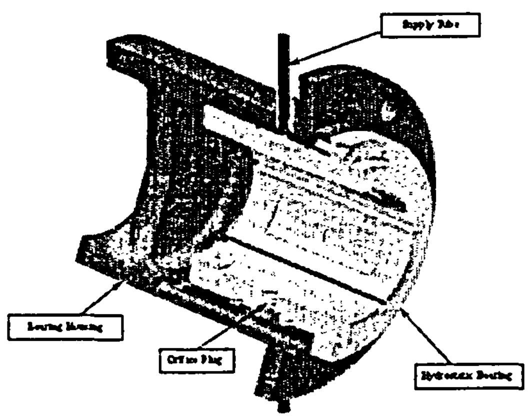
Original Hydrostatic Bearing

- Bearing includes tight clearances (0.006 inch to 0.007 inch) at edges of pockets
- Debris in supply water may be larger than clearance and accumulate in the bearing pocket
- Degradation of bearing performance may impact pump operation



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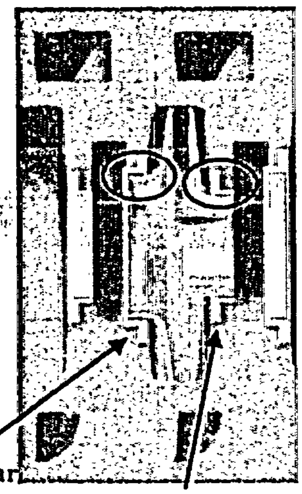
Close Clearances Wear

- Pump design includes tight clearances
  - Central volute bushing (0.006 inch to 0.007 inch)
  - Hydrostatic bearing (0.006 inch to 0.008 inch)
  - Wear rings (0.009 inch to 0.010 inch)
- Debris in water may increase rate of wear of the fine clearances
  - Increased clearances could result in operation at critical speeds
  - Increased clearances could decrease hydraulic performance capability



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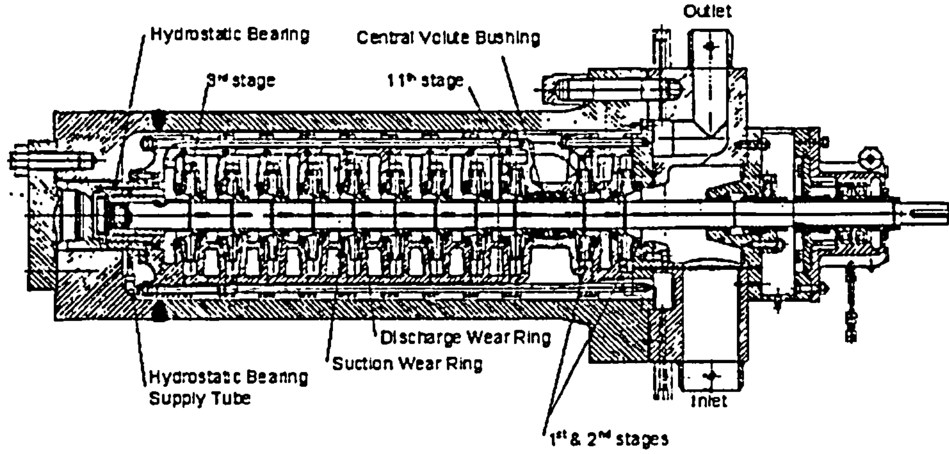
HPI Pump Configuration



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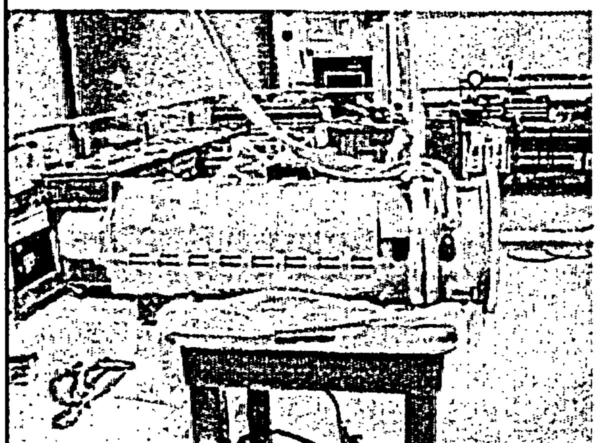
HPI Pump Internal Assembly

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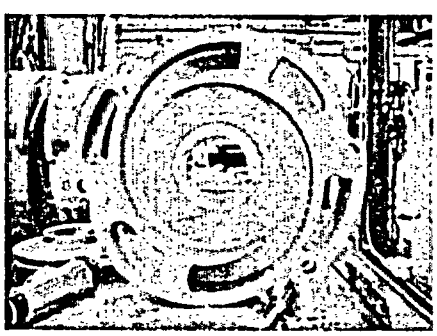
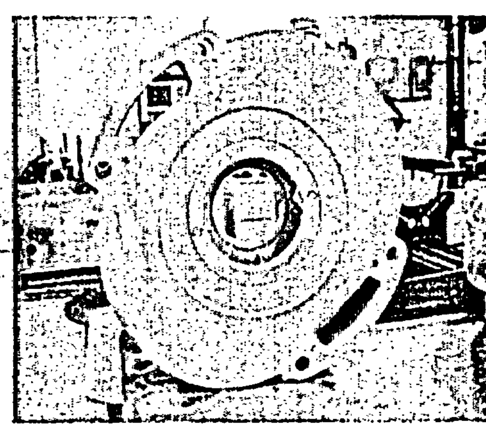
HPI Pump Volute





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Original Hydrostatic Bearing

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Resolution Objective

- Implement a resolution plan that fully resolves HPI pump debris issue that
  - Modifies only the HPI pump
  - Assures compliance with existing licensing basis, procedures, Updated Safety Analysis Report, and design basis documents
  - Meets requirements of Technical Specifications

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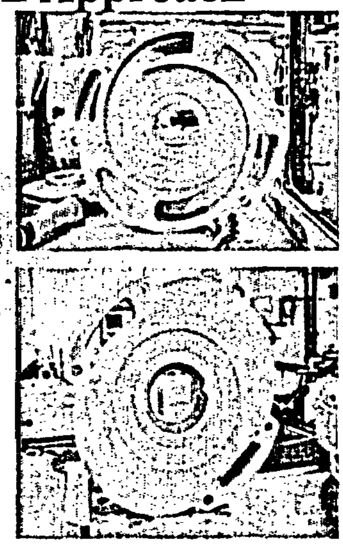
Initial Modification Approach



- Modifications
  - Install self-flushing strainer on volute to prevent plugging of hydrostatic bearing supply line orifice
  - Move supply line take-off to suction side of volute

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Initial Modification Approach

- Key Assumptions to be verified
  - Strainer would be self-flushing and remain clear of debris
  - Debris larger than bearing clearance would be crushed by bearing and pass through clearance
  - Wear of close clearances would be minimal and uniform
  - Pump operation at critical speeds would not cause vibration or other operational challenges

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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

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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

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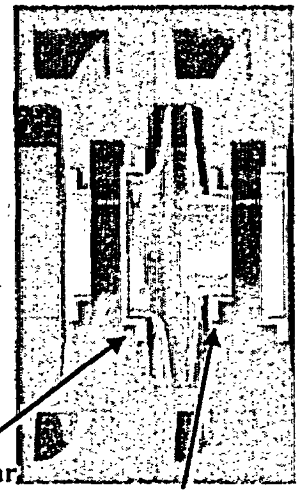
Revised Design Concept
(Continued)

- •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



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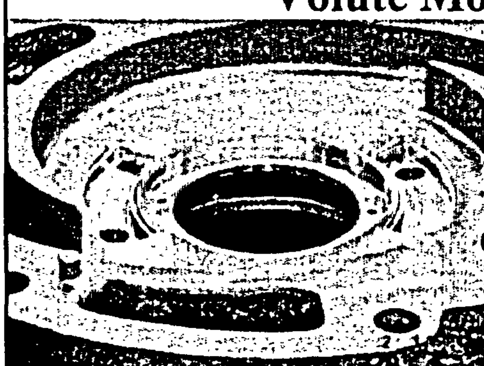
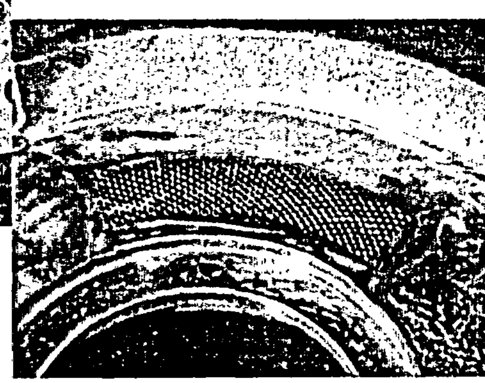
Volute Modifications





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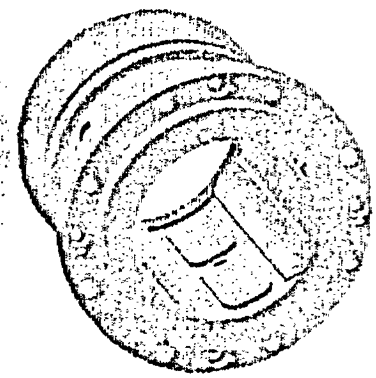
Revised Design Concept
(Continued)

- 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

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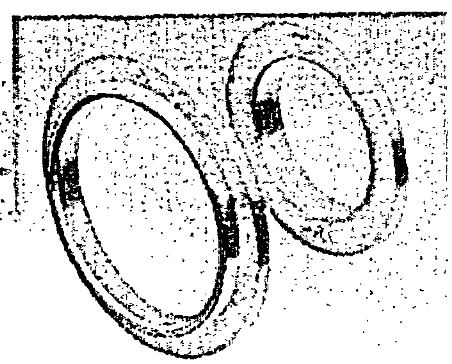
Revised Design Concept
(Continued)

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



Suction and Discharge Wear Rings

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Analysis and Qualification Testing

Bob Coward

MPR Associates

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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

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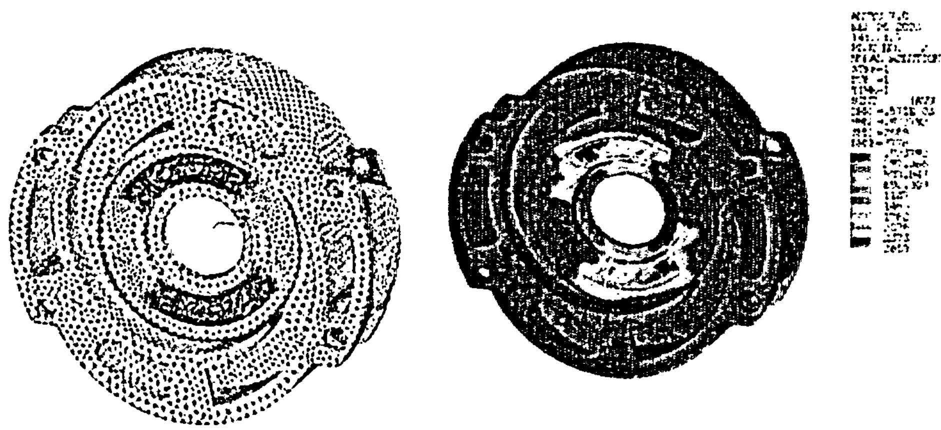
Volute Finite Element Model



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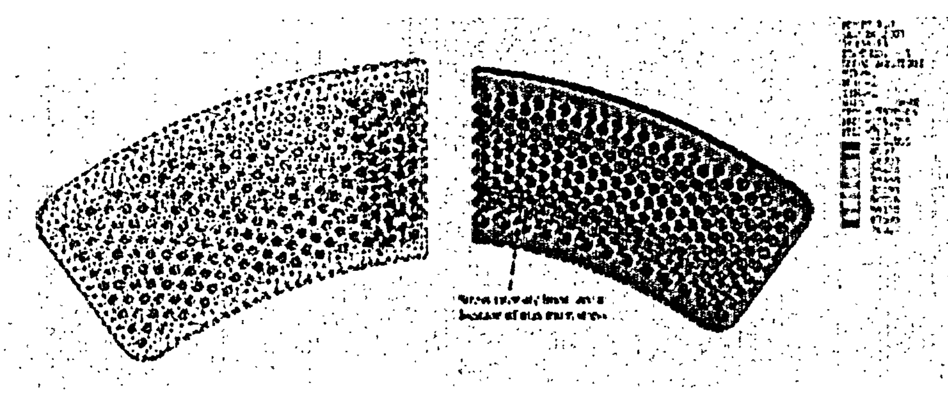
Strainer Finite Element Analysis Stress



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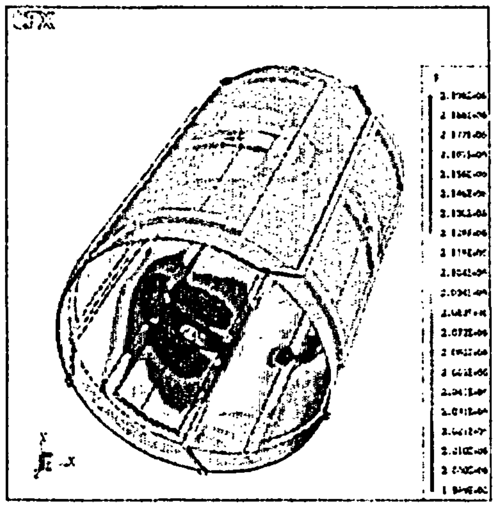
Hydrostatic Bearing Analysis



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Failure Mode and Effects Analysis

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

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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

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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

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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

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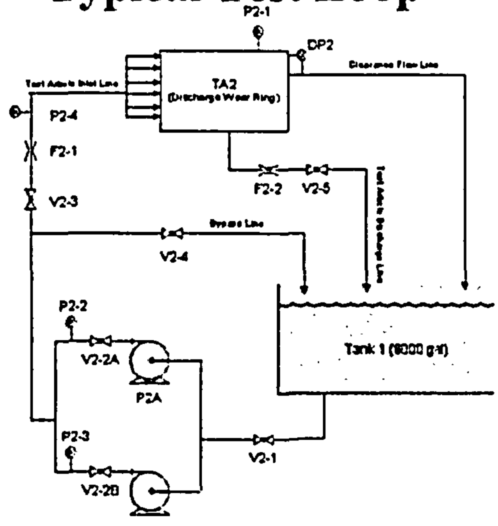
Typical Test Loop



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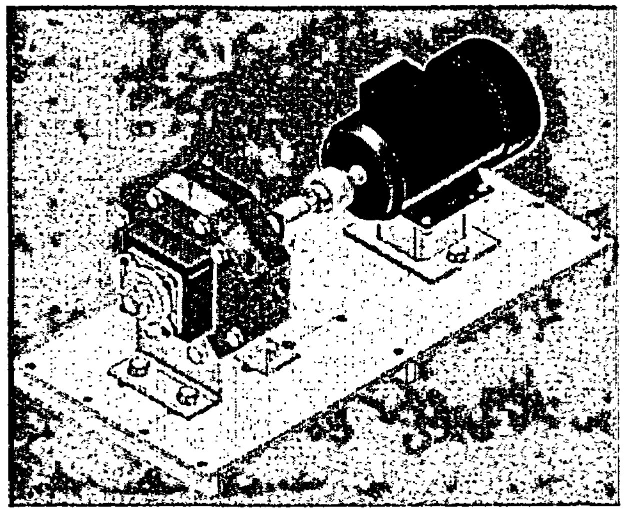
Suction Wear Ring Test Fixture



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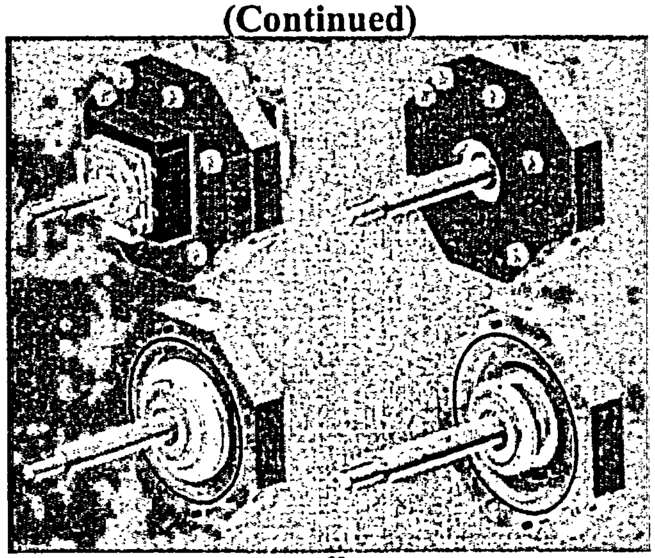
Suction Wear Ring Test Fixture (Continued)



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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

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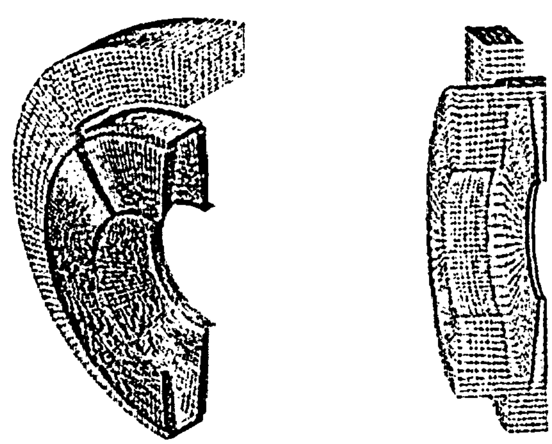
CFD Modeling HPI and Loop 5 Pumps



HPI Pump Loop 5 Pump

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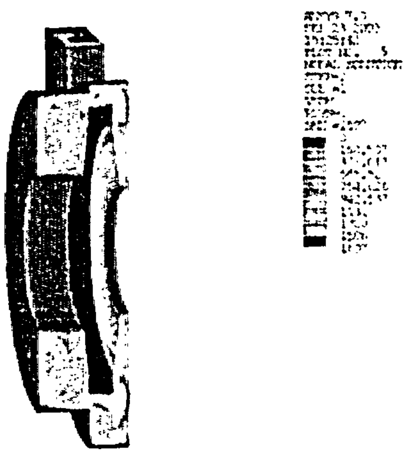
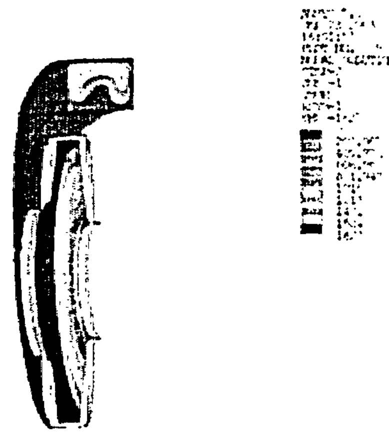
CFD Analysis Results





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HPI Pump Operating Conditions

- •SBLOCA operating conditions most challenging, but minimal debris
- •LBLOCA most challenging debris, but not needed for short term cooling
- •LBLOCA long term cooling (boron precipitation control) combines worst case debris with low flow/high head operation – testing performed for these operating conditions

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Debris Characterization Approach

- Analyses based on debris generation and debris transport analyses for containment sump modification, as well as NRC-sponsored research
- Critical parameters, and their acceptance ranges, are defined for each debris type
- Commercial-off-the-shelf (COTS) materials selected to match critical characteristics
- Debris handling procedure addresses initial loading, sampling, and re-loading

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Debris Characterization Analysis

- Considered short term and long term debris generation
- Considered debris transport to sump strainer
- Particle sizes selected to increase pump degradation
- Debris "recipe" includes:
  - Fiber (based on quantities after removal from containment)
  - Rust
  - Qualified and unqualified coatings
  - Dirt and dust
  - Concrete particles

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Conservatisms in Analysis

- No credit for filtering of small debris on sump strainer surfaces
- Particle/fiber sizes biased toward increasing potential for pump degradation
- All miscellaneous fibers assumed to transport to sump
- All unqualified coatings are assumed to fail and become debris in post-LOCA environment

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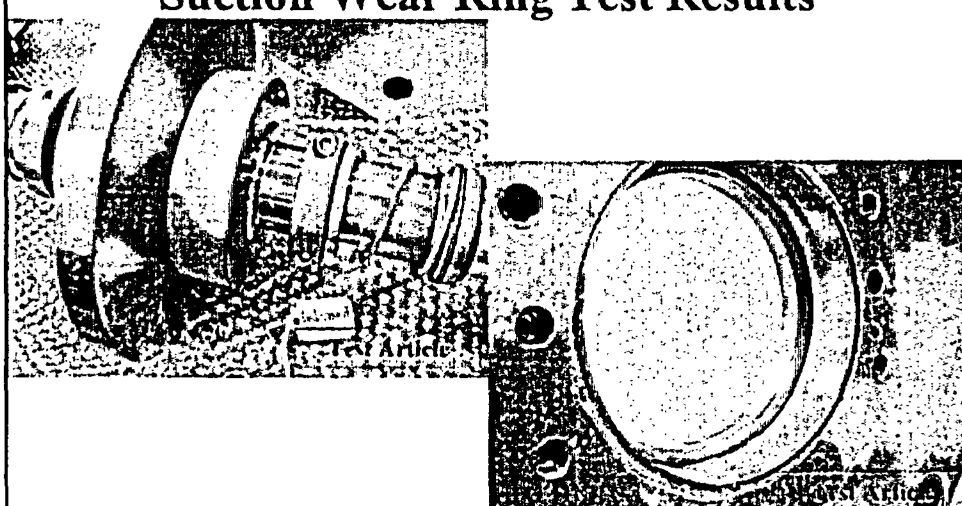
Suction Wear Ring Test Results



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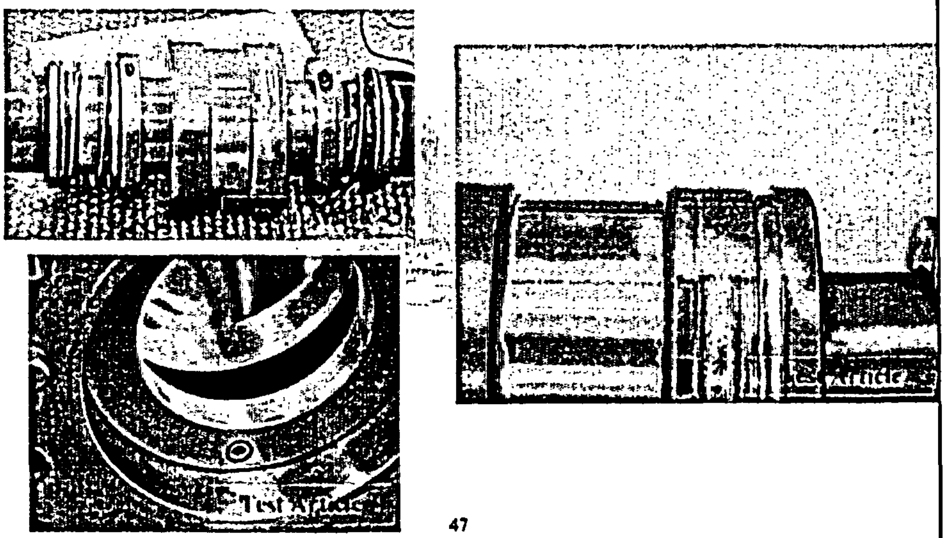
Discharge Wear Ring Test Results



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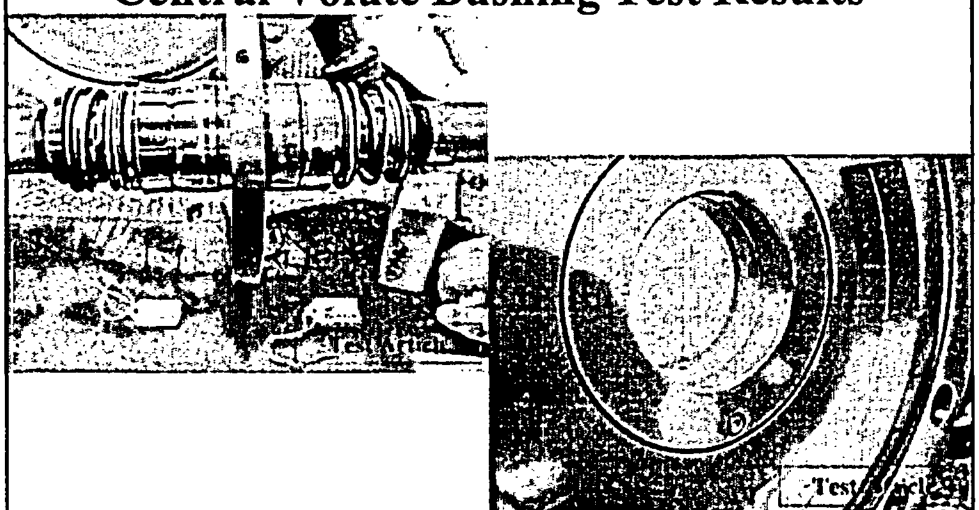
Central Volute Bushing Test Results



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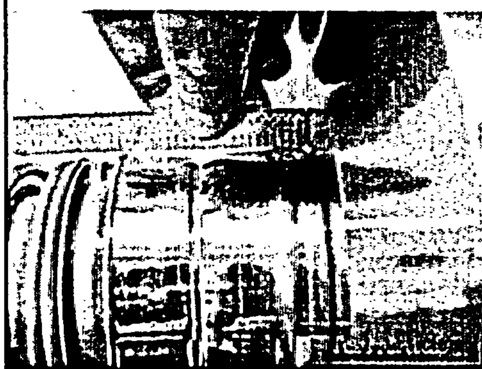
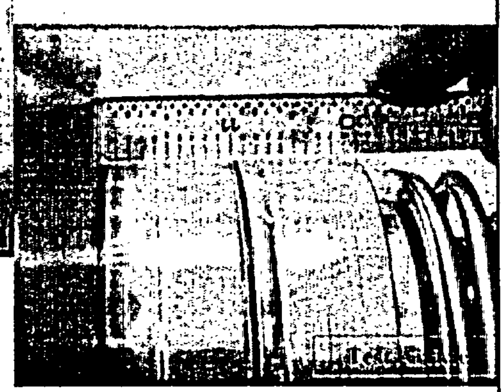
Central Volute Bushing Test Results





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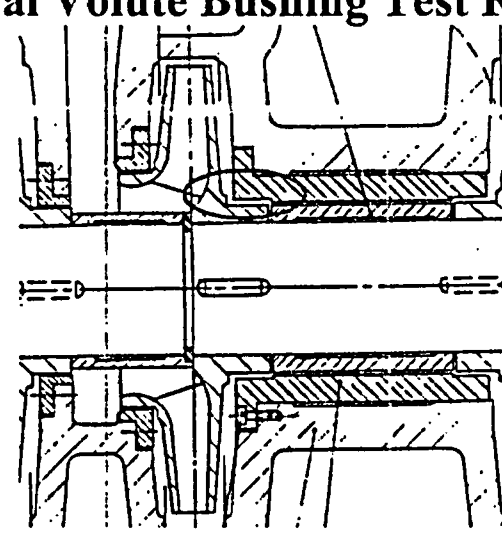
Central Volute Bushing Test Results



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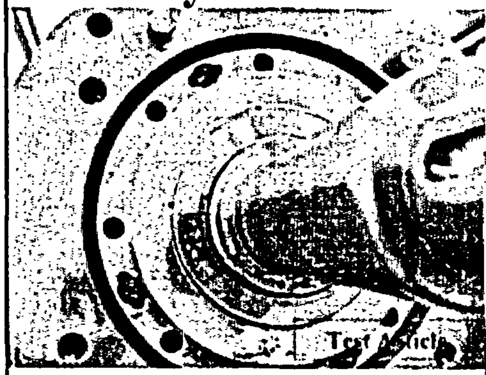
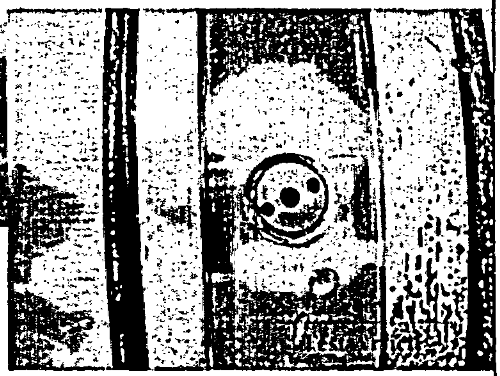
Hydrostatic Bearing Test Results





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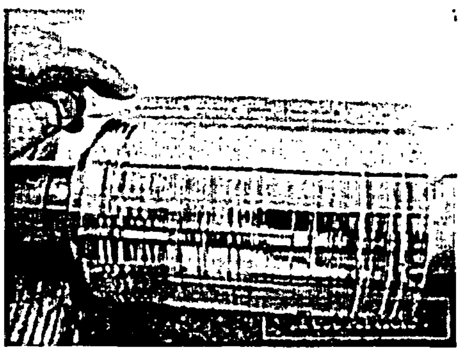
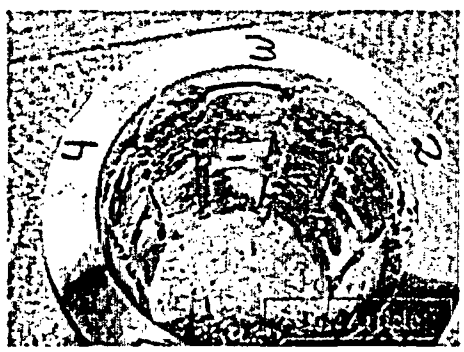
Hydrostatic Bearing Test Results





21 Days Testing

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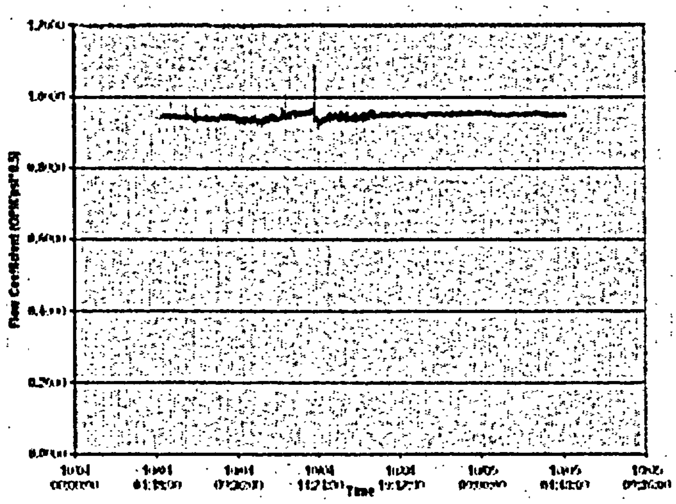
Hydrostatic Bearing Test Results



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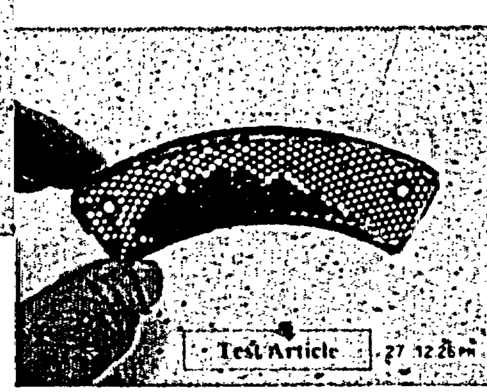
Strainer Test Results



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Qualification Testing Results Summary

- Suction Wear Ring
  - –Minimal wear on wear ring and impeller hub
  - –Little impact on leakage flow
- Discharge Wear Ring
  - –Minimal wear on wear ring
  - –Abrasive "grooving" on impeller hub from plugging, small wear elsewhere on hub
  - –Essentially no impact on pump performance

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Qualification Testing Results Summary
(Continued)

- Central Volute Bushing
  - –Minimal wear on bushing
  - –Abrasive wear on shaft sleeve from plugging
  - –Leakage flow depends on plugging and axial extent of abrasive wear
- Hydrostatic Bearing
  - –Minimal wear on bearing
  - –Abrasive wear on shaft sleeve
  - –Bearing flow remained adequate (~ 5% decrease)
- Strainers
  - –Essentially constant flow throughout test

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Performance Analyses

- Rotordynamics Analysis
  - To demonstrate that vibration levels for the worn condition of all pump parts are acceptable
  - Preliminary analysis results show acceptable results
- Hydraulic Analysis
  - To demonstrate the pump hydraulic performance in the worn condition is acceptable
  - Preliminary analysis results show considerable margin

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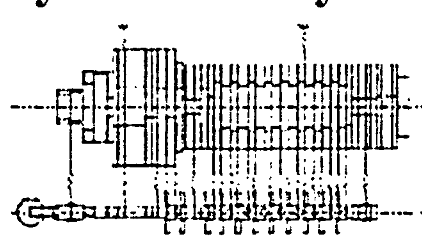
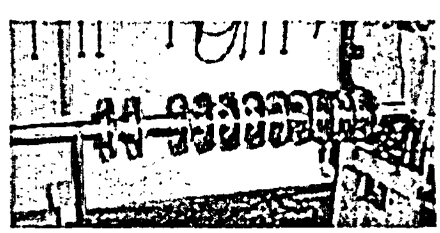
Rotordynamics Analysis Model





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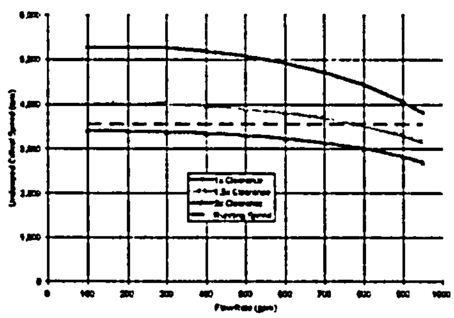
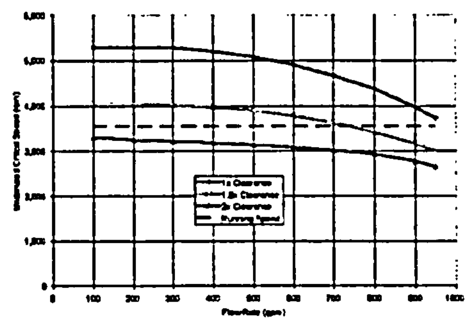
Critical Speed Analysis



Original Hydrostatic Bearing



Replacement Hydrostatic Bearing

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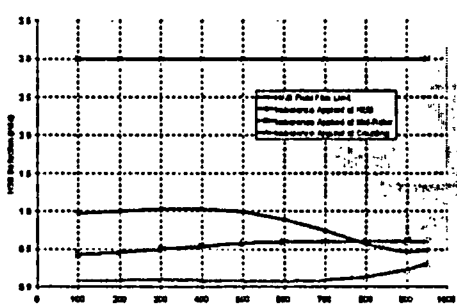
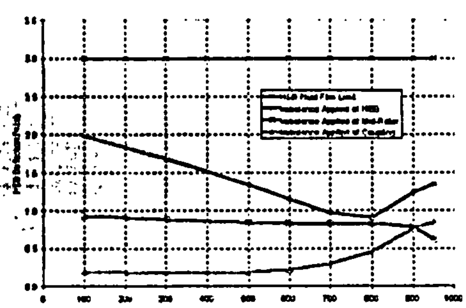
Forced Response Analysis



75% Central Volute Bushing Length



50% Central Volute Bushing Length

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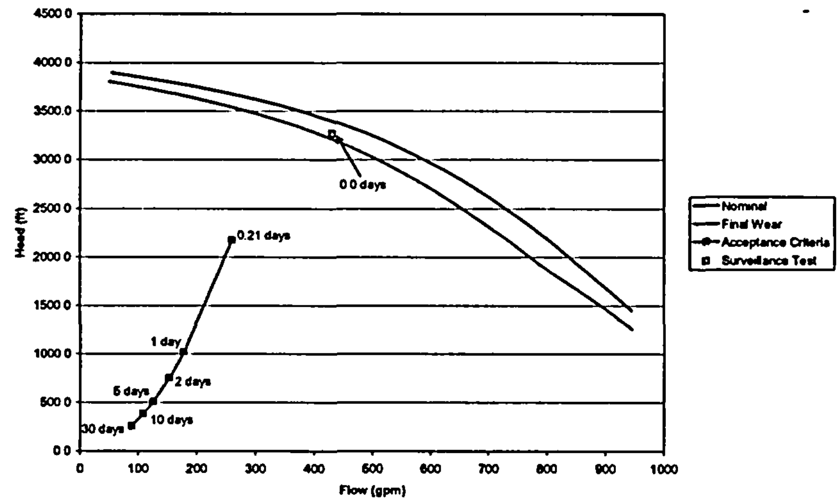
Hydraulic Performance Analysis



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French Experience

- French PWRs use similar class pump for make-up/HPI
- Nuclear Safety Authority requested validation pumps would operate satisfactorily in emergency conditions
  - Comprehensive testing performed in 1980-1981
  - Pump design modified to increase debris tolerance
- Main design features were:
  - Moved hydrostatic bearing take-off to discharge side of volute
  - Hardfaced close clearances
  - Modified hydrostatic bearing pocket design to "H" bearing
  - Replaced central volute bushing with hydrostatic bearing

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French Experience
(Continued)

- Davis-Besse HPI Pump modifications comparable to French modifications, with additional measures to improve debris tolerance

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Overall Approach Summary

Concern	Modifications	Testing	Analysis
HSB orifice and pocket plugging	•Installed strainer to filter debris •Moved HSB take-off to low debris location •Included debris escape grooves in HSB pockets	•Mock-up testing of strainer demonstrated adequate flow •Mock-up testing of HSB demonstrated adequate flow	•Completed structural analysis of volute/strainer •Completed HSB hydraulic analysis •FMEA •Completed evaluation of mock-up fixtures
Close clearance wear	•Installed replacement hardfaced parts to minimize wear	•Mock-up testing of new parts determined worn condition •In-plant testing of worn pump demonstrated acceptable performance	•Rotordynamics analysis demonstrated worn condition and new HSB are acceptable •Hydraulic analysis demonstrated worn condition is acceptable

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Major Project Conservatisms

- Defense-in-depth approach to ensure satisfactory pump performance
- Mock-up testing did not include filtering effect of discharge wear ring for hydrostatic bearing flow
- Mock-up testing maintained initial debris concentrations for entire test – extreme measures were required to prevent settling and hideout
- All miscellaneous debris assumed to be transportable fiber
- Simulated coating materials in mock-up testing significantly stronger than containment coatings

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Project Status

- Modification design completed, finalizing design change package
- Mock-up testing completed, finalizing data analysis
- Preliminary rotordynamic and hydraulic analysis completed, awaiting finalization of test report
- Pump modifications in progress

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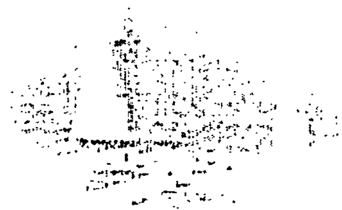
Conclusion



Gary Leidich

President and Chief Nuclear Officer - FENOC

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Conclusion

- Modifications, along with associated analysis and testing, demonstrates that the HPI pumps will perform their safety functions