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AGING AND SERVICE WEAR OF AUXILIARY FEEDWATER PUMPS FOR PWR NUCLEAR POWER PLANTS*

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To be presented at the
Nuclear Plant Aging Research Program
Research Review Group Meeting

March 21, 1989

*Research sponsored by Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission under Interagency Agreements DOE 1886-8082-8B with the U.S. Department of Energy under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

AGING AND SERVICE WEAR OF AUXILIARY FEEDWATER PUMPS FOR PWR NUCLEAR POWER PLANTS

SUMMARY

This paper describes investigations on auxiliary feedwater pumps being done under the Nuclear Plant Aging Research (NPAR) Program. Objectives of these studies are to (1) identify and evaluate practical, cost-effective methods for detecting, monitoring, and assessing the severity of time-dependent degradation (aging and service wear); (2) recommend inspection and maintenance practices; (3) establish acceptance criteria; and (4) help facilitate use of the results. Emphasis is given to identifying and assessing methods for detecting failure in the incipient stage and to developing degradation trends to allow timely maintenance, repair or replacement actions.

The activities embrace two study phases and application guideline development. Phase 1 studies provide baseline information for use in subsequent portions of the study. Failure modes and causes attributable to aging and service wear are identified, as are measurable parameters (or functional indicators) for potential use in assessing operational readiness, detecting incipient failure, and establishing degradation trends.

Phase 2 studies complete the failure cause identification and verification and rank the cause in terms of importance. Recommendations are developed for inspection, surveillance, and condition monitoring (ISCM) methods and for establishing maintenance or replacement needs.

Under application guideline development, guidance will be given on the use of recommendations developed in Phase 2. In addition, criteria are to be developed for operational readiness determination and for establishing maintenance or replacement needs.

Auxiliary feedwater pumps have both safety and nonsafety roles. The safety role is to supply feedwater to the steam generators when a unit trip occurs coincident with a loss of off-site power and when dissipation of reactor decay heat is required. The nonsafety role is operation during plant startups and shutdowns or when only a small amount of feedwater is required.

The work to date has addressed pump types; materials of construction; operational requirements; stressors; failure modes and causes; inspection, surveillance and monitoring methods; and maintenance practices. Failure mode and cause identification was the central element of the work thus far; inspection, surveillance and monitoring method and maintenance practice recommendations are tied directly to failure modes and causes.

Failure modes and causes associated with aging and service wear were identified on the basis of information from a number of sources. These sources were: design details; operating requirements; experience as revealed by data bases (such as the Licensee Event Report file, Nuclear Plant Reliability Data System, and Nuclear Power Experience); post-service examinations; and in-situ assessments.

Three failure modes were defined for AUXFPs: failure to operate, failure to operate as required, and external leakage. Twenty failure causes were identified and ranked in importance according to three measures: frequency of occurrence, influence on operational readiness, and interaction consequences. The latter refers to one cause activating other causes. The four highest ranking causes are (1) bearing wear, corrosion, and breakage; (2) shaft seal deterioration and breakage; (3) binding between rotor and stationary parts; and (4) impeller wear and breakage.

Measurable parameters were also identified, and 17 ISCM methods were recommended. All of the latter are based on the current state-of-the-art, and several are in current use. Measurements required by Section

XI of the ASME Boiler and Pressure Vessel Code are a subset of those recommended. The recommended ISCM methods plus thorough inspection, which includes periodic pump disassembly and inspection (not currently practiced), will provide needed bases for decision making regarding acceptability as well as maintenance, repair, and replacement needs.

Maintenance and replacement practice recommendations are extensions of current practices. Both regular inspection (nondisassembly) and periodic disassembly and inspection at specific intervals are to be important parts of the maintenance program. The recommendations include corrective and preventive maintenance practices, which are currently in use, and predictive maintenance. These recommendations can yield significant benefits, including reduced component downtime, forced outage avoidance, improved plant efficiency, and reduced maintenance costs.

Although not covered by the original scope of investigation, consequences of operation and testing at low-flow rates were carefully reviewed. This review revealed that accelerated aging and wear can result from low-flow operation; in addition, aging and service wear, including accelerated aging and wear, can go undetected when pumps are tested at low-flow rates (currently practiced in many instances) because such testing does not provide information required for detecting and assessing degraded states.

Results from the AUXFP studies are being used in ASME Operation and Maintenance of Nuclear Power Plant standard development work as well as for development of general guidelines related to centrifugal pump operation and testing. Thus far, the results have been used in deriving bases for two NRC published documents.

The application guideline development portion will help to ensure maximum use of and benefit from the products of the investigations carried out. Therefore, application guidelines are very important and should be addressed on a timely basis.

REFERENCES

1. M. L. Adams and E. Makay, Aging and Service Wear of Auxiliary Feedwater Pumps for PWR Nuclear Power Plants. Vol. 1, Operating Experience and Failure Identification, NUREG/CR-4597, Vol. 1 (ORNL 6282/V1), July 1986.

2. D. M. Kitch et al., Aging and Service Wear of Auxiliary Feedwater Pumps for PWR Nuclear Power Plants. Vol. 2, Aging Assessments and Monitoring Method Evaluations, NUREG/CR-4597, Vol. 2 (ORNL-6282/V2), June 1988.

3. W. L. Greenstreet, Low-Flow Operation and Testing of Pumps in Nuclear Power Plants, to be published.

ORNL-WSC-8129 ETD

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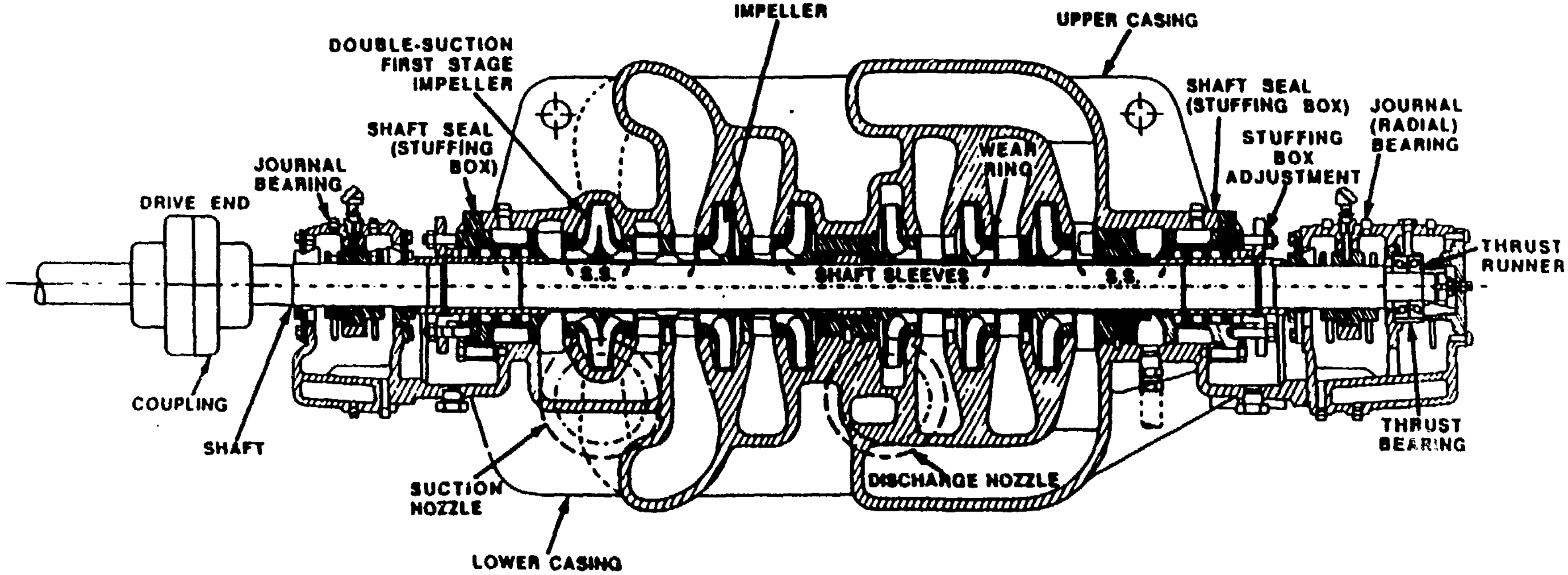
ISCM METHODS ARE CENTRAL TO COMPREHENSIVE AGING ASSESSMENTS AND MAINTENANCE GUIDANCE

NUCLEAR PLANT AGING RESEARCH PROGRAM
RESEARCH REVIEW GROUP MEETING

MARCH 21, 1989



IMPELLER
UPPER CASING
DOUBLE-SUCTION FIRST STAGE IMPELLER
SHAFT SEAL (STUFFING BOX)
JOURNAL (RADIAL) BEARING
STUFFING BOX ADJUSTMENT
SHAFT SEAL (STUFFING BOX)
JOURNAL BEARING
WEAR RING
DRIVE END
THRUST RUNNER
S.S.
SHAFT SLEEVES
S.S.
COUPLING
SHAFT
THRUST BEARING
DISCHARGE NOZZLE
SUCTION NOZZLE
LOWER CASING

AUXILIARY FEEDWATER PUMPS PLAY SAFETY AND NON-SAFETY ROLES

SAFETY ROLE: SUPPLY FEEDWATER TO STEAM GENERATORS

- WHEN UNIT TRIP OCCURS COINCIDENT WITH LOSS OF OFF-SITE POWER
- REQUIRED TO DISSIPATE REACTOR DECAY HEAT

NON-SAFETY ROLE: OPERATION DURING STARTUPS AND SHUT-DOWNS, OR WHEN ONLY A SMALL AMOUNT OF FEEDWATER IS REQUIRED

NPAR PROGRAM ACTIVITIES EMBRACE TWO STUDY PHASES AND APPLICATION GUIDELINES DEVELOPMENT

TOPICS BEING COVERED IN AUXILIARY FEEDWATER PUMP STUDIES ARE:

PHASE 1. BACKGROUND INFORMATION

FAILURE MODE AND CAUSE IDENTIFICATION

PHASE 2. RECOMMENDATIONS OF INSPECTION, SURVEILLANCE, AND CONDITION MONITORING (ISCM) METHODS

RECOMMENDATIONS OF INSPECTION AND MAINTENANCE PRACTICES

GUIDELINES FOR APPLICATION

RECOMMENDATIONS FOR CONSENSUS STANDARDS AND REGULATORY GUIDES

OPERATIONAL READINESS ACCEPTANCE CRITERIA

CRITERIA FOR MAINTENANCE, REPAIR OR REPLACEMENT

DISCUSSIONS ARE ENHANCED BY DIVIDING ASSEMBLIES INTO SEGMENTS AND COMPONENT PARTS

PUMP SEGMENT	PARTS	
ROTATING ELEMENTS	SHAFT IMPELLERS MISC. SPACERS	FASTENERS THRUST RUNNERS
NONROTATING INTERNALS	DIFFUSERS OR VOLUTES RETURN CHANNELS	WEAR SURFACES FASTENERS
PRESSURE-CONTAINMENT CASING	UPPER CASING LOWER CASING FASTENERS	SUCTION AND DISCHARGE NOZZLES
MECHANICAL SUBSYSTEMS	BEARINGS SEALS	THRUST BALANCER COUPLING FASTENERS
SUPPORT	BASE FRAME	FASTENERS

AUXILIARY FEEDWATER PUMPS CAN FAIL IN THREE MODES

FAILURE TO OPERATE	ROTOR DOES NOT ROTATE
FAILURE TO OPERATE AS REQUIRED	A. FAILURE TO PROVIDE REQUIRED HEAD-CAPACITY PUMPING CHARACTERISTICS B. CRITICAL PARAMETER MEASUREMENTS OUTSIDE ACCEPTABLE RANGES
EXTERNAL LEAKAGE	ESCAPE OF CONTAINED MEDIUM FROM COMPONENT BOUNDARY

EXPERIENCE PROVIDES IDENTIFICATION OF FAILURE CAUSES RELATED TO AGING AND SERVICE WEAR

PUMP SEGMENT	FAILURE CAUSE
ROTATING ELEMENTS	BINDING BETWEEN ROTOR AND STATIONARY PARTS
	SHAFT BREAKAGE
	IMPELLER WEAR, BREAKAGE
	THRUST RUNNER WEAR, BREAKAGE
	FASTENER LOOSENING, BREAKAGE
NONROTATING INTERNALS	STRUCTURAL DAMAGE TO STATIONARY VANES (DIFFUSER OR VOLUTE)
	WEAR SURFACE WEAR, EROSION, CORROSION, SEIZING
	FASTENER LOOSENING, BREAKAGE

EXPERIENCE: DATA BASE INFORMATION, DIRECT EXPERIENCE, POST-SERVICE EXAMINATIONS, AND IN-SITU ASSESSMENTS

EXPERIENCE PROVIDES IDENTIFICATION OF FAILURE CAUSES RELATED TO AGING AND SERVICE WEAR (Cont'd)

PUMP SEGMENT	FAILURE CAUSE
PRESSURE-CONTAINMENT CASING	LEAK AT CASING SPLIT
	LEAK AT CASING RUPTURE DISK
	SUCTION NOZZLE } LEAK, BREAKAGE
	DISCHARGE NOZZLE } LEAK, BREAKAGE
	FASTENER LOOSENING, BREAKAGE
MECHANICAL SUBSYSTEMS	BEARING WEAR, CORROSION, BREAKAGE
	SHAFT SEAL DETERIORATION, BREAKAGE
	THRUST BALANCER GALLING, SEIZING
	COUPLING WEAR, BREAKAGE
	FASTENER LOOSENING, BREAKAGE
SUPPORT	BASE FRAME BREAKAGE
	FASTENER LOOSENING, BREAKAGE

EXPERIENCE: DATA BASE INFORMATION, DIRECT EXPERIENCE, POST-SERVICE EXAMINATIONS, AND IN-SITU ASSESSMENTS

FAILURE CAUSE RANKING PROVIDED BASIS FOR ESTABLISHING PRIORITIES

FAILURE CAUSE	RANKING[A]
BEARING WEAR, CORROSION, BREAKAGE	1
SHAFT SEAL DETERIORATION, BREAKAGE	2
BINDING BETWEEN ROTOR AND STATIONARY PARTS	3
IMPELLER WEAR, BREAKAGE	4
THRUST BALANCER WEAR, GALLING, SEIZING	5
WEAR SURFACE WEAR, EROSION, CORROSION, SEIZING	6
SHAFT BREAKAGE	7
FASTENER LOOSENING, BREAKAGE (ROTATING ELEMENTS)	8

[A] BASED ON FREQUENCY OF OCCURRENCE, INTERACTION CONSEQUENCES, AND INFLUENCE ON OPERATIONAL READINESS

A VARIETY OF MEASURABLE PARAMETERS CAN BE USED IN FAILURE CAUSE IDENTIFICATION (EXAMPLE FOR ONE FAILURE MODE)

FAILURE MODE	PUMP SEGMENT	FAILURE CAUSES	MEASURABLE PARAMETERS
FAILURE TO OPERATE AS REQUIRED	ROTATING ELEMENTS	IMPELLER WEAR, BREAKAGE	APPEARANCE, ROTOR VIBRATION, DELIVERED FLOW
		THRUST RUNNER WEAR	TRANSMITTED TORQUE, ROTATIONAL SPEED, APPEARANCE
		FASTENER LOOSENING, BREAKAGE	APPEARANCE, BOLT TORQUE
	NONROTATING INTERNALS	STRUCTURAL DAMAGE TO STATIONARY VANES (DIFFUSER OR VOLUTE)	DELIVERED FLOW, APPEARANCE, VIBRATION
		WEAR-SURFACE BINDING	TRANSMITTED TORQUE, VIBRATION
		WEAR-SURFACE WEAR, EROSION, CORROSION	APPEARANCE, DELIVERED FLOW, CLEARANCE, VIBRATION
		FASTENER LOOSENING BREAKAGE	APPEARANCE, BOLT TORQUE

MEASURABLE PARAMETER VERSUS DEGRADATION CORRELATIONS ARE INSTRUCTIVE

PARAMETER	DEGRADATION
DEVELOPED HEAD } DELIVERED FLOW }	CHANGES IN OVERALL MACHINE HEALTH
ACOUSTIC EMISSION	WEAR OF ROLLING ELEMENT BEARINGS, COUPLING, AND GEARS; SHAFT SEAL DETERIORATION; ROTOR RUBBING
BEARING TEMPERATURE	BEARING WEAR
ROTOR AXIAL POSITION	THRUST BALANCER, THRUST RUNNER, OR BEARING WEAR
BALANCE RETURN LINE FLOW	INTERNAL CLEARANCE INCREASE
VIBRATION	WEAR OF WEAR SURFACES, IMPELLER, BEARINGS, COUPLING; LOOSE FASTENERS

EXAMPLES OF PARAMETER MONITORING RECOMMENDATIONS ILLUSTRATE RESULTS OF ISCM EVALUATION

- ROTOR VIBRATION (INCLUDING ORBITAL)*
- BALANCE RETURN LINE FLOW
- DEVELOPED HEAD AND DELIVERED FLOW*
- ROTOR AXIAL POSITION
- ACOUSTIC, OR STRESS WAVE, EMISSION
- BEARING TEMPERATURE*
- DIMENSIONAL INSPECTION

INSPECTION AND MAINTENANCE RECOMMENDATIONS ARE PREDICATED ON USE OF ISCM METHODS

- RECOMMENDED INSPECTION PRACTICES ARE IN THREE CATEGORIES
  1. REGULAR NONDISASSEMBLY
  2. CONDITION MONITORING
  3. PERIODIC DISASSEMBLY
- MAINTENANCE PRACTICE RECOMMENDATIONS INVOLVE THREE TYPES
  1. CORRECTIVE
  2. PREVENTATIVE
  3. PREDICTIVE

LOW-FLOW OPERATION CAN BE A MAJOR CONTRIBUTOR TO AGING AND SERVICE WEAR

- BYPASS LINES ARE USED DURING SYSTEM OPERATION AND FOR OPERATIONAL READINESS DETERMINATION
- BYPASS FLOW RATE IN MANY PLANTS IS 5 TO 15% BEP FLOW (CURRENT GUIDANCE IS 25% MINIMUM)
- HYDRAULIC INSTABILITY INDUCED DEGRADATION RESULTS
- FLOW IS TOO LOW AND RUNNING TIME IS TOO SHORT FOR MEANINGFUL TEST RESULTS
- FLOW RATE DECISIONS WERE HEAVILY INFLUENCED BY ECONOMICS AND PUMP TEMPERATURE RISE CONSIDERATIONS

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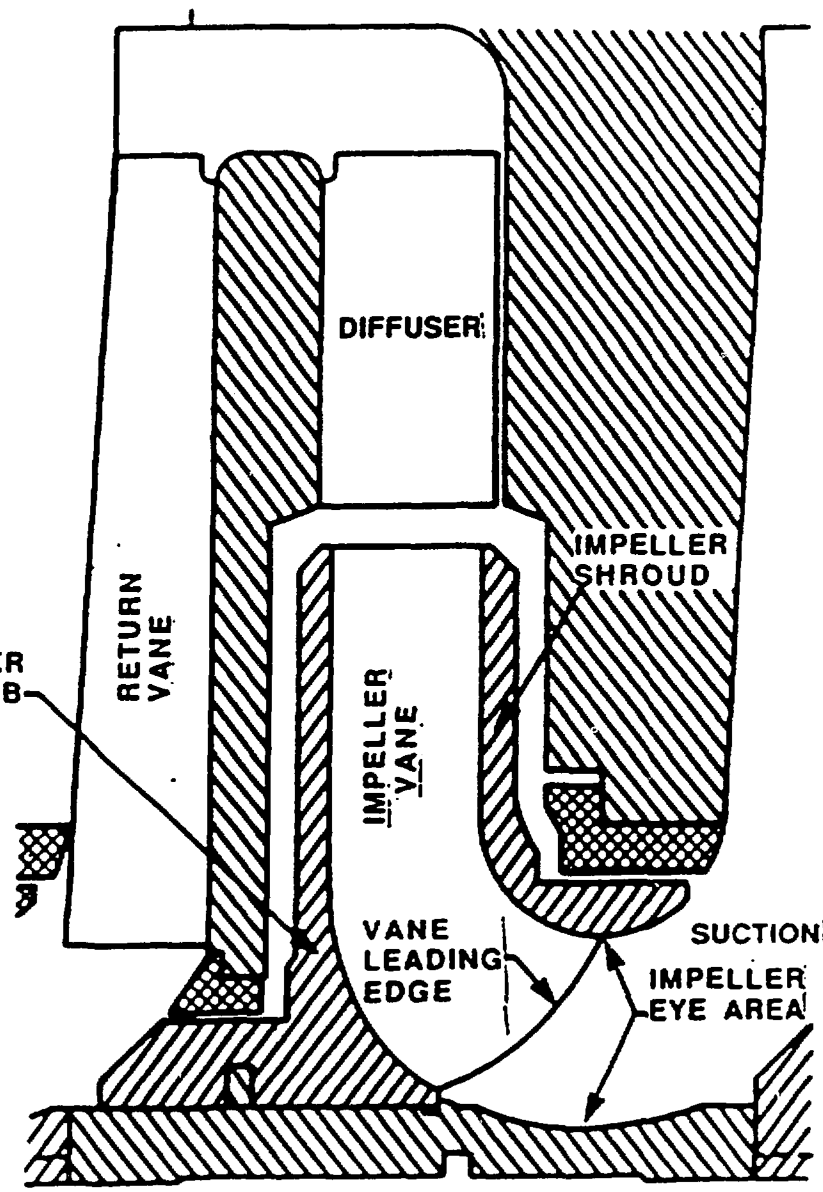
PUMP STAGE TERMINOLOGY



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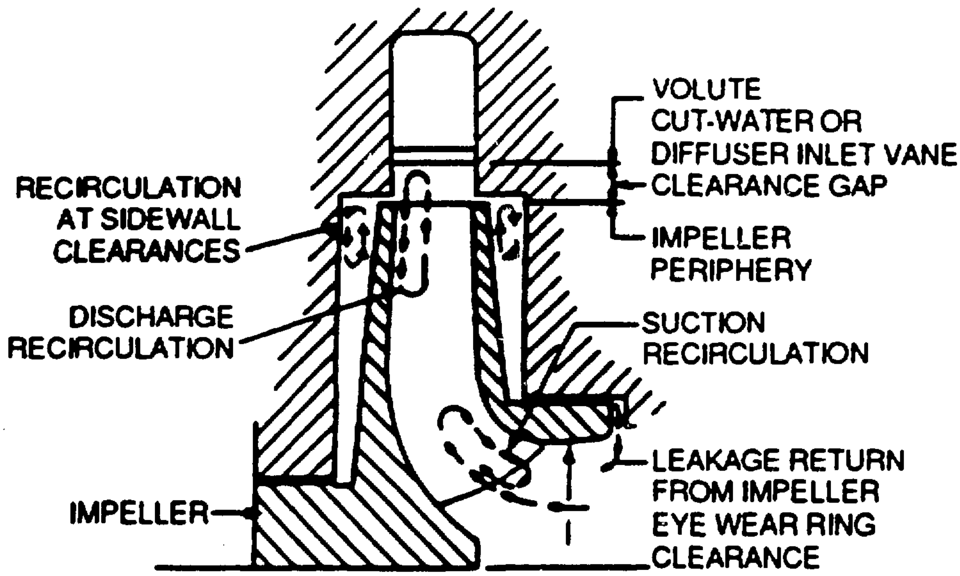
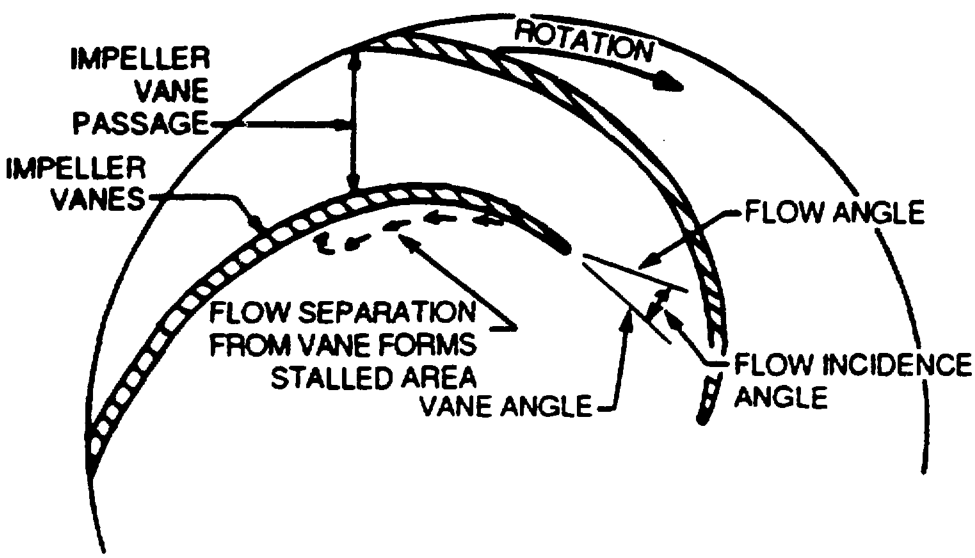
HYDRAULIC INSTABILITY IS HIGHLY DETRIMENTAL





LOW-FLOW OPERATION PRODUCES ACCELERATED AGING THROUGH HYDRAULIC INSTABILITY

- GIVES RISE TO:
  - FLOW RECIRCULATION IN SUCTION AND DISCHARGE REGIONS
  - HYDRAULIC STALL IN IMPELLER AND DIFFUSER VANE REGIONS
  - VORTEX COLLAPSE AND CAVITATION NEAR IMPELLER-VOLUTE, OR DIFFUSER, INTERFACE
  - FLUCTUATING AXIAL MOVEMENT OF ROTOR DUE TO PRESSURE FLUCTUATIONS ON IMPELLER SHROUD AND HUB
- CONSEQUENCES:
  - CAVITATION EROSION
  - UNSTABLE HEAD-FLOW CHARACTERISTICS
  - BREAKAGE OF IMPELLERS, SHAFTS, AND CUTWATERS OR DIFFUSER VANES
  - FAILURES OF SEALS, BEARINGS, AND AXIAL THRUST BALANCING DEVICES
  - VIBRATION FAILURES

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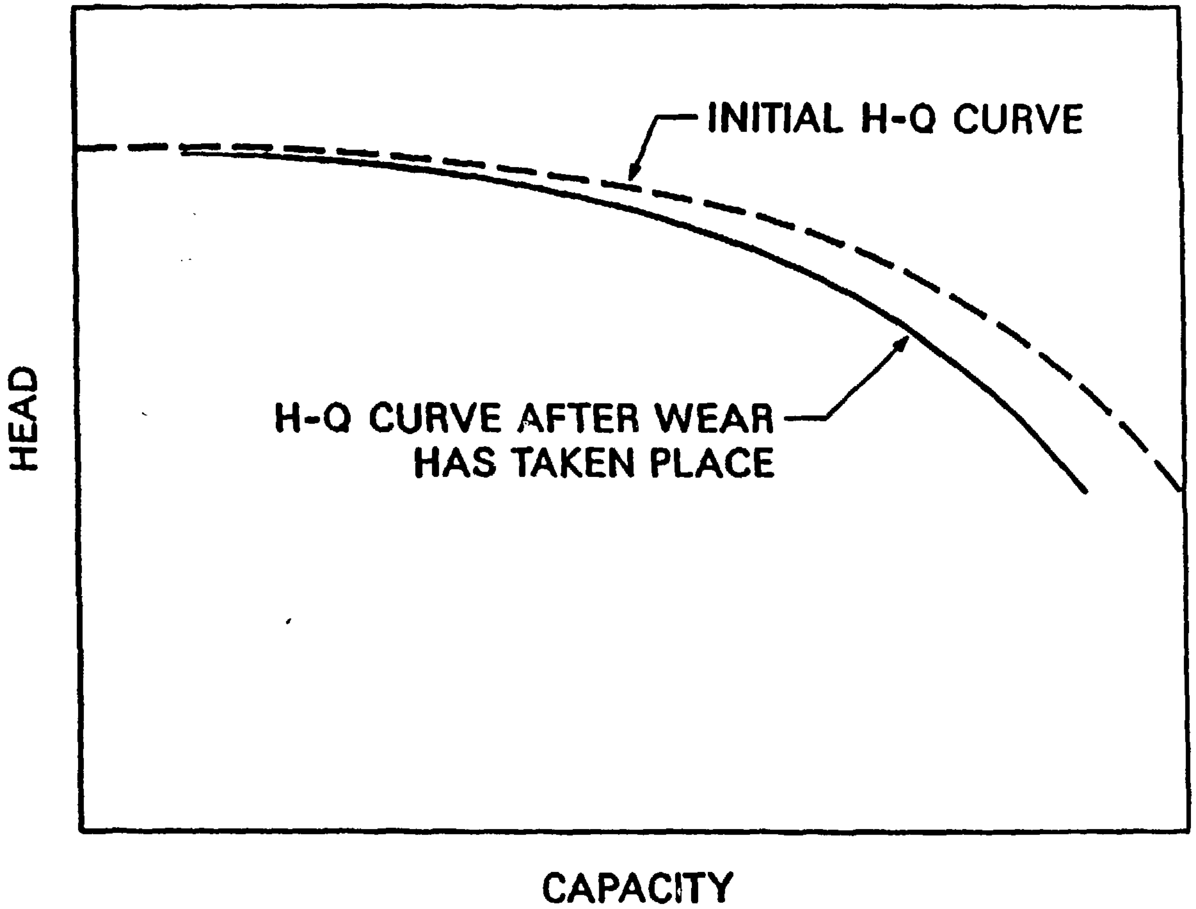
CHARACTERISTIC CURVES FOR PUMPS INDICATE PERFORMANCE DEGRADATION



LOW-FLOW OPERATION AND TESTING SHOULD BE RECONSIDERED

- ACCEPTABLE FLOW RATES SHOULD BE ESTABLISHED JOINTLY BY OWNERS AND MANUFACTURERS
- NEW INFORMATION FROM SOURCES ADDRESSING HYDRAULIC INSTABILITY ISSUES SHOULD BE USED
- OTHER ALTERNATIVES, e.g., WESTINGHOUSE PROPOSED FULL-FLOW PUMP TESTS DURING PLANT POWER OPERATION, SHOULD BE EXAMINED

RESULTS FROM AUXILIARY FEEDWATER PUMP INVESTIGATIONS ARE HAVING IMPACT

PROVIDED IMPUT TO DEVELOPMENT OF ASME OPERATION AND MAINTENANCE STANDARD ON PUMPS

PROVIDED GUIDANCE TO NRC OFFICE OF NUCLEAR REACTOR REGULATION IN REVIEW OF RELIEF REQUESTS

CONTRIBUTED BASIC INFORMATION USED IN PREPARATION OF

- NRC BULLETIN No. 88-04: POTENTIAL SAFETY-RELATED PUMP LOSS, MAY 5, 1988
- NRC INFORMATION NOTICE No. 89-08: PUMP DAMAGE CAUSED BY LOW-FLOW OPERATION, JANUARY 26, 1989

NPAR STUDIES PROVIDE BASES FOR ASSESSING AND MITIGATING AGING AND SERVICE WEAR DEGRADATION

- RECOMMENDATIONS ON INSPECTION, SURVEILLANCE, AND CONDITION MONITORING METHODS HAVE BEEN DEVELOPED
- RECOMMENDATIONS ON INSPECTION AND MAINTENANCE PRACTICES HAVE BEEN MADE
- LOW-FLOW OPERATION WAS SHOWN TO HAVE POTENTIAL FOR CAUSING ACCELERATED AGING AND WEAR
- INADEQUANCIES OF LOW FLOW TESTING WERE DISCUSSED
- DEVELOPMENT OF APPLICATION GUIDELINES SHOULD BE ADDRESSED FORTHWITH FOR MAXIMUM BENEFIT FROM PRODUCTS