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**WATER TESTING
OF
THE INDUCER PUMP**

ERDA Research and Development Report

*Prepared for the United States
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Division of Reactor Development and Demonstration,
under Contract Number EY-76-C-03-0824*

Rockwell International

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I. INTRODUCTION AND SUMMARY

The inducer pump (Figure 1), designed and fabricated as a test article to evaluate the inducer/impeller pump concept for providing improved suction performance of large sodium pumps, met or exceeded all performance goals.

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Figure 1. Inducer Pump Assembly

The inducer stage in front of the centrifugal impeller dramatically reduces the size of pumps (see Figure 2). It was demonstrated that the inducer can operate at suction specific speeds in excess of 35,000, whereas conventional centrifugal pumps have demonstrated capability to only 12,000.

The inducer pump employs several components of the 2000 and 4000 gpm NaK pumps from the Connecticut Aircraft Nuclear Engine Laboratory (CANEL) Programs. Use of the volute, thermal barrier and shaft oil seal from the CANEL pumps allowed acceleration and cost reduction of the Inducer Pump Program.

Prior to testing the inducer pump, goals were set for critical net positive suction head (at 3% pump head loss), inducer/impeller efficiency, and inducer/impeller developed head. The water test program demonstrated that the inducer pump exceeded these goals. A summary of the test results compared to the range of goals is presented in Table 1. Critical net positive suction head (NPSH) and developed head exceeded the most desirable extreme values, and inducer/impeller efficiency was above the mid-range of the goal

Figure 2. Effects of Pump Suction Performance on Pump Size

TABLE 1
COMPARISON OF WATER TEST RESULTS AND PREDICTED GOALS

Speed = 2,497 rpm (75% of design)
Flow Rate = 2,126 gpm (75% of design)

Pump Parameters	Test Results	Range of Goals	
		Minimum Parameter Value	Maximum Parameter Value
1. Inducer/Impeller Developed Head (ft)	335	270	308
2. Inducer/Impeller Efficiency (%)	82	78	85
3. Critical NPSH at 3% head fall off (ft)	4.7	5.06	6.75
4. Critical NPSH Scaled to 100% Speed (ft)	8.4	9	12
5. Suction Specific Speed at critical NPSH	36,068	27,487	34,106

extremes. The inducer/impeller developed head was higher than the maximum goal by 8.5%. At the design flow/speed ratio, and 75% speed, 335 ft was developed by the inducer and impeller, while 308 ft was the goal maximum.

The suction specific speed of the inducer was higher than the goal maximum by ~6%. At the design flow/speed ratio, and 75% speed, a suction specific speed of 36,068 was achieved (compared to the goal maximum of 34,100).

The inducer/impeller efficiency of 82% exceeded the minimum goal of 78% by ~4%. At higher flow rates, the data showed continued improvement in efficiency.

Pump operation was stable over the complete test range of head vs flow. At 25% design speed, the pump was tested from 59 to 170% of design flow/speed ratio. At 40% design speed, the pump was tested from 62 to 166% of design flow/speed ratio. At 75% design speed (the maximum capability of the water test loop), the pump was tested from 67 to 130% of design flow/speed ratio.

The pump was very quiet and exhibited minimal vibration during operation. During the entire water test program, the highest vibration level recorded at the speed frequency was 0.024 g's rms compared to a conservative test criteria limit of 0.1 g's rms.

Even after exposing the inducer pump to over 10 hours' operation at an NPSH margin* of 100% or less, and a total running time of about 38-1/2 hours, the blading surfaces were in excellent condition. Post-test examination revealed that the inducer and impeller blading surfaces were virtually unaffected by the testing, since the machining marks were visually unaltered. Surface replicas were taken at 118 stations prior to water testing, and were taken at 4 stations after water testing. (A lesser post-test number were taken due to the excellent condition of the blading and to minimize cost and schedule for inspection.) The number of replicas to be taken after sodium testing will be dictated by visual inspection of the blading at that time.

$$* \text{ NPSH margin} = \left(\frac{\text{Operating NPSH}}{\text{Critical NPSH}} - 1 \right) \times 100\%$$

II. INDUCER PUMP DESCRIPTION

The major components of the inducer pump are shown in Figure 3. The volute and thermal barrier are components from the 4000 gpm CANEL pumps, but were modified to meet the requirements of the inducer pump. Two volutes were employed, based on program schedule interactions; one for the water test facility and one for the sodium test facility. The thermal barrier was modified to (1) add baffles at the outer diameter to prevent cover gas circulation and possible distortion due to induced thermal differences, and (2) provide a routing path for instrumentation. The shaft oil seal assembly is from the 2000 gpm CANEL pump.

Fluid enters the subscale test article at the bottom suction nozzle, flows directly into the inducer, exits axially from the inducer, and enters the centrifugal impeller, from which it exits radially. Fluid exiting the centrifugal impeller flows into a special test adapter whose vanes were designed to match with the discharge flow. The existing CANEL volute passages act as a partial flow diffuser. The inducer and impeller, scaled from the full-size cold leg designs, were fabricated from Type 304H stainless-steel forgings.

A pressure transducer port, located in the rear face of the test adapter, monitors the impeller discharge pressure. During water testing at the Hydraulic Test Facility, a special total pressure probe (Kiel) was installed in this port at the impeller discharge. This probe was chosen because of its wide range flow-direction measurement capability.

The subscale inducer-centrifugal impeller thrust balancing is accomplished with radial vanes located on the back (rear shroud) of the impeller. This method was selected because it offered an optimum thrust balancing capability, within the design limitations imposed by use of the existing CANEL thermal barrier. A 2% penalty on efficiency resulted from its use.

The inducer and impeller are driven by a solid Type 304H stainless steel shaft. The shaft passes into the high-pressure discharge area of the pump through a labyrinth seal. Fluid leakage passing through the shaft labyrinth seal is collected in an overflow sump and is discharged through a 6-in. overflow nozzle in the volute.

Figure 3. Inducer/Impeller Test Article

The CANEL shaft seal is mounted in the center flange assembly. The seal uses a bellows which is mounted to a bronze stationary face. A steel rotating face is sealed to the shaft with two O-rings. A slinger and standpipe arrangement is incorporated to form a large oil catch basin at the top of the thermal barrier. One existing 1-1/2-in. emergency oil drain is provided in this catch basin. Four additional 1-in. emergency oil drains were added to the catch basin to assure that failure of the shaft oil seal would not allow oil to enter the pumped-fluid regions of the pump.

The shaft is supported radially in the bearing housing by two high-precision (RBEC-5), high-speed radial roller bearings. Each bearing is lubricated by three high-pressure jets whose flow is externally adjustable. The downward thrust load is taken by a high-precision (ABEC-7), high-speed, split inner race angular contact bearing. The bearing is designed to be self-centering around the axis of the upper radial roller bearing. The unit is designed to take thrust in either direction in case of an accidental thrust reversal. The thrust bearing is lubricated by three high-pressure oil jets whose flow is externally adjustable.

The subscale pump is driven through a flexible coupling by a variable-speed electric drive. For convenience, the entire pumping element assembly, consisting of the bearing housing, thermal barrier, impeller, inducer, and test adapters, is removable from the volute. Twenty 1-3/8-in. studs retain the removable assembly to the volute. Sealing is accomplished by a stainless-steel ring joint gasket. This allows the removable assembly to be installed either in the water test volute or in the sodium test volute, as required. Further information on the Inducer Pump is provided in Ref. 3.

The inducer pump is shown in Figure 4 installed for water testing in the Hydraulic Test Facility. This facility is described in the "Test Facility Description" Section III of this report.

Figure 4. Test Article Installed at Hydraulic Test Facility

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III. TEST FACILITY DESCRIPTION

The initial Hydraulic Test Facility (HTF) used for the AI subscale inducer and impeller water performance testing was that shown by the P&I Diagram of Figure 5. The facility was modified during the test program to include a de-aeration tank, as shown in Figure 6 and by the P&I Diagram of Figure 7. Simplified schematics for both of these test facility configurations are shown in Figures 8 and 9.

A. MAIN FLOW LOOP (Piping, Valves, and Flowmeters)

The main flow loop (MFL) consisted of 8- and 10-in. stainless-steel (Types 304 and 316) piping and various control valves. The pipe sizing varied around the loop, with the exception that the pump inlet piping from FCV-9 to the Plexiglas viewing section at the inducer inlet was all 10-in. Piping of 8-in. diameter was used primarily from the pump discharge to FCV-10. Reducers from 10 to 8 in. were used at all MFL control valve locations, since they (FCV-8, -9, -10, and -11) were all 8-in. valves.

All control valves were Fisher globe-type valves. FCV-10 and FCV-11 were fitted with operators, and were capable of remote position control at the facility test console. Figure 10 shows FCV-11 and the final inlet piping with the pump installed. FCV-8 and FCV-9 were used with local position control capability. Specific data for each of these valves are as follows:

- 1) FCV-8 Fisher Globe Valve
 8 in., 300 lb rated, Type 316 SS body
 S/N 4951892
- 2) FCV-9 Fisher Globe Valve
 8 in., 300 lb rated, Type 316 SS body
 S/N 4951893
- 3) FCV-10 Fisher Globe Valve
 8 in., 150 lb rated, DF8M body
 S/N 482496
 Fisher Controls local air diaphragm
 operator, Serial 4951895,
 Type 657-8-V, Size 46

Figure 5. HTF P&I Diagram Prior to Addition of Deaeration Tank

Figure 6. Hydraulic Test Facility at LMEC

Figure 7. HTF P&I Diagram After Addition of Deaeration Tank

Figure 8. HTF Schematic Prior to Addition of Deaeration Tank

Figure 9. HTF Schematic After Deaeration Tank Addition

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Figure 10. FCV-11 and Pump Inlet Piping

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- 4) FCV-11 Fisher Globe Valve
8 in., 150 lb rated, CF8M body
S/N 4951894
Fisher Controls local air diaphragm
operator, Serial 4951894,
Type 657-8-V, Size 46

Pump inlet and discharge flows were measured by FE-8 and FE-10, respectively. Both were 8-in. turbine-type flowmeters. Specific data for each are as follows:

- 1) FE-8 N. A. A. - X10
Model SK8228
S/N 203874
- 2) FE-10 Fisher Porter
Model - 10C1511A

B. TEST PUMP DRIVE SYSTEM

The pump drive consisted of three major components, the drive motor, fluid drive, and right-angle drive. Figure 11 shows these components. Specific data for these are as follows:

1) Drive Motor:*

Manufacturer: U. S. Electrical Motors Division of Emerson Electric
Uniclosed Motor, Type H, 1800 rpm
Serial J1421842
Rated at 275 hp, 3-phase, 60 Hz

2) Fluid Drive:

Manufacturer: American Standard Gyrol
Rated at 250 hp, Variable Speed to 1800 rpm
Size 171, Type VS, Class 2
Serial 73-171F2BF7

3) Right-Angle Drive:

Manufacturer: Arrow Gear Company
Type: Johnson Right-Angle Drive
Rated at 200 hp at 2500 rpm, Ratio 2-to-3
S/N 51667S200

*The available 275 hp drive motor is capable of producing 75% of pump design speed. Procurement of a larger motor to obtain 100% design speed was not considered cost or schedule effective.

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Figure 11. Pump Drive Components

C. TANKS

Two tanks were used at the HTF for the AI pump tests. The deaeration tank (DA) was installed as a flow-through component in the MFL. To promote deaeration of the flowing water, it used a riser pipe which tended to make the return flow go to the liquid surface. With a vacuum cover gas pressure (e. g., 15-in. Hg), the DA tank functioned to remove dissolved air from the water in the test loop. The T-1 tank served as a water supply tank (before the DA tank was added) and as a drain tank for the pump overflow. These tanks are briefly described as follows:

1) Deaeration Tank:

Capacity: 7600 gal.

Configuration: 17-1/2 ft OAL, 9 ft OD, Elliptical Heads

Rating: 150 psi

Material: Type 304 SS

2) T-1 Tank:

Capacity: 1000 gal.

Rating: None (vented to atmosphere)

Material: Type 304 SS

D. COMPUTER-CONTROLLED DATA ACQUISITION SYSTEM

The HTF used a Hewlett-Packard Digital Data Acquisition System (DDAS) that was functionally centered around a digital computer with 32,000 words of 16-bit core memory.

System input/output, programming, and control peripherals included a high-speed paper tape reader, a high-speed paper tape punch, a heavy-duty terminal printer unit, a 1/2-in. digital magnetic tape unit with NRZI 9-track, 800 BPI format, an analog signal input/output subsystem with 16 channels of low-level (0 to 1 V) and 16 channels of high-level (0 to 10 V) input, and a digital clock display. The system is depicted in the block diagram of Figure 12.

Data from measurements were multiplexed and digitized by the analog subsystem, and were recorded by the magnetic tape unit and included time of

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Figure 12. Data Acquisition System Diagram

day and other test information. Scan intervals were set by operator input. Table 2 lists the parameters which were measured and used by the DDAS. Table 3 shows other parameters which were measured and manually recorded.

Software was developed to provide the option of outputting selected parameters to the terminal directly from the analog subsystem either as raw values in millivolts or engineering units. A performance parameter data reduction program, also developed to provide real-time output, summarized test and test article conditions.

Data monitoring during testing was accomplished by an alarm program which continuously determined if two consecutive 30 sample averages for pump torque exceeded a limit value. If this occurred, an alarm message was printed.

TABLE 2
HTF DAS MEASUREMENT LIST

AI I.D. No.	P&ID Tag No.	Description	Parameter Range	Accuracy (% = F.S.)	Transducer Manufacturer
P _{1A}	PT-3	Pump Inlet Pressure at Station 1A	0-50 psia	±1% F.S.	Taber
P _{1B}	PT-2	Pump Inlet Pressure at Station 1B	0-50 psia	±1% F.S.	Taber
P ₂	PT-1	Pump Discharge Pressure at Station 2	0-200 psig	±1% F.S.	Taber
P ₃	P _t T-1	Inducer/Impeller Total Pressure at Station 3	0-200 psig	±2% F.S.	Taber
P ₇	PT-7	Cover Gas Pressure	0-50 psia	±2% F.S.	Taber
P ₈	PT-8	Bearing Cavity Pressure	0-20 psig	±2% F.S.	Taber
T ₁	TE-2	Pump Inlet H ₂ O Temp	50-150°F	±3°F	
T ₂	TE-1	Pump Discharge H ₂ O Temp	50-150°F	±3°F	
T ₃	TE-6100	Pump Oil Inlet Manifold Temp	0-300°F	±3°F	
T ₄	TE-7	Pump Oil Outlet Manifold Temp	0-300°F	±3°F	
T ₅	TE-3	Lower Bearing Temp	0-300°F	±3°F	
T ₆	TE-4	Upper Axial Bearing Temp	0-300°F	±3°F	
T ₇	TE-5	Upper Radial Bearing Temp	0-300°F	±3°F	
T ₈	TE-6	Thermal Baffle Stand Pipe Temp	0-300°F	±3°F	
P ₄	P _d T-1	Pump Delta Pressure Between Stations 2 & 1A	0-150 psid	±1% F.S.	Validyne
Q ₁	FT-8	Pump Inlet Flow	0-2500 gpm	±1% F.S.	Potter
Q ₂	FT-10	Pump Discharge Flow	0-2500 gpm	±1% F.S.	Fisher Porter
N ₁	ST-1	Pump Speed	0-3000 rpm	±1% F.S.	Himmelstein
M ₁	T _Q T-1	Pump Torque	0-10 k lb-in.	±2% F.S.	Himmelstein
P _{1C}	PT-3A	Pump Inlet Pressure Alternate at 1A	0-25 psia	±1% F.S.	CEC

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TABLE 3
HTF-AI PUMP TESTING MANUALLY
RECORDED PARAMETERS

Tag No.	Description	Parameter Range	Transducer Manufacturer	Accuracy (% = F. S.)
V-1	Pump Inlet Position A Vibration	0-25 kHz	Endevco	±5%
V-2	Pump Inlet Position B Vibration	0-25 kHz	Endevco	±5%
V-3	Center Flange Position C Vibration	0-25 kHz	Endevco	±5%
V-4	Center Flange Position D Vibration	0-25 kHz	Endevco	±5%
FI-6100	Total Oil Flow	*	Annubar	*
PI-4	Inlet Manifold Oil Pressure	0-200 psig	Ashcroft	±2%
Q-5	Lower Bearing Oil Flow	0-4 gpm	RCM Industries	±10%
Q-6	Upper Axial Bearing Oil Flow	0-4 gpm	RCM Industries	±10%
Q-7	Upper Radial Bearing Oil Flow	0-4 gpm	RCM Industries	±10%
Q-8	Seal Coolant Oil Flow	0-20 gpm	RCM Industries	±10%
Q-9	Thermal Barrier Coolant Oil Flow	0-10 gpm	RCM Industries	±10%
Pos. FCV-8	Valve FCV-8 Position	0-100%	Fisher Controls	±3%
Pos. FCV-9	Valve FCV-9 Position	0-100%	Fisher Controls	±3%
Pos. FCV-10	Valve FCV-10 Position	0-100%	Fisher Controls	±3%
Pos. FCV-11	Valve FCV-11 Position	0-100%	Fisher Controls	±3%

*Inoperative

IV. TEST PROGRAM SUMMARY

The test program fulfilled the requirements specified in the Request for Test.⁽¹⁾ Performance verification and specific test objectives which established the test requirements were:

- 1) Demonstration of inducer and impeller operating capability in a low NPSH environment
- 2) Quantification of the suction (NPSH) performance of the pump
- 3) Characterization of the head-flow (H-Q) and efficiency curves at selected speeds
- 4) Steady-state endurance (8 h) demonstration
- 5) Noise spectrum measurements during all tests
- 6) Checkout of oil seal assembly and bearing assembly operation.

The test log is shown in Table 4. For the first eleven tests, the loop was run without a deaeration (settling) tank. The H-Q data obtained were within approximately 1% of the final performance data, even though substantial amounts of air were being pumped. This condition became known when initial cavitation tests were run; also, it was very clear when a viewing section was added at the pump inlet. The presence of significant bubbles in the inlet line was shown. A deaeration tank was then added by LMEC, and tests beginning with Test No. 12 were with no substantial air entrainment.

Testing was initiated on January 28, 1977, and completed on April 11, 1977. Figure 13 shows the accumulated operation duration for the test program. Figure 14 shows the pump operating durations at various pump test speeds. Figure 15 shows these same test durations vs speed for various head-flow operation regions.

TABLE 4
INDUCER PUMP WATER TEST LOG

Test No	Test Date	Type Test	Target Speed (% Design)	Flow Rate (% Design)	Comments
1	1-28-77	Checkout	25	100	Successful test, all pump assembly and facility equipment okay
2	1-31-77	Checkout	75	100	Test terminated due to high water level in thermal barrier
2A	2-2-77	Repeat No. 2	75	100	Successful test after facility modification to provide unrestricted overflow line
3	2-4-77	H-Q	25	54 to 143	Successful test
4	2-7-77	H-Q	40	72 to 132	Successful test
5	2-8-77	H-Q	75	82 to 108	Successful test, high flow (148% design) obtained at 40% speed at start of test
6	2-10-77	Cav	75	100	Pump lost head at about 15 ft NPSH. Cause later determined to be entrained air in water
7	2-14-77	Cav	75	109	Unsuccessful test, entrained air in water caused pump to lose head prematurely
8	2-16-77	Cav.	60	125, 140, 90	Unsuccessful test, entrained air in water caused pump to lose head prematurely
9	2-18-77	Cav.	75	102	Test No. 6 repeated with discharge throttling change to avoid possible in-leakage into test loop, also GN ₂ used for pressurization rather than air. Still lost head prematurely.
10	3-4-77	Cav	75	100	Plastic viewing section installed at pump inlet. Numerous bubbles in water even at high (35 ft) NPSH. Lost head prematurely.
11	3-7-77	Cav.	75	100	Held vacuum on system over weekend. Deaerated water by running pump at 600 rpm and 20 ft NPSH for 1/2 hr. Only 2 ft improvement in NPSH. Determined that deaeration tank was required.
12	3-30-77	Checkout	75	100	With deaeration tank added, entrained air bubbles reduced significantly (~2 orders of magnitude), successful test
13	3-30-77	H-Q	25 40 75	59 to 170 62 to 166 67 to 130	Successful test
14	3-31-77	Cav.	75	100	
15	4-1-77	Cav.	75	110	
16	4-7-77	Cav.	77	90, 106, 100	Successful test
17	4-11-77	8 h	75	100	Successful test

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Figure 13. Inducer Pump Accumulated Operating Duration at HTF

Figure 14. Inducer Pump Operating Durations at Various Test Speeds

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Figure 15. Inducer Pump Operating Durations vs Speed and Q/N

V. PERFORMANCE TEST RESULTS

The inducer pump test results met or exceeded all predicted pump performance parameters. The predicted parameters at 75% design speed are listed in Table 5.

TABLE 5
PREDICTED PERFORMANCE PARAMETERS AT 75%
SPEED IN WATER

Speed (rpm)	2497 ^{+2.5%} -4.2%
Inlet Flow Rate (gpm)	2126 ^{+4.2%} -2.5%
Inducer and Impeller Developed Head (ft)	284 ^{+8.5%} -5.0%
Operating NPSH (ft)	10.12 $\pm$ 1.12
Critical NPSH (ft)	5.06 ^{+1.60} -0
Inducer/Impeller Efficiency (%) (Based on inlet flow and corrected for bearing and oil seal power losses)	83 ⁺² -5

A summary of the performance of the pump at design Q/N and various speeds is shown in Table 6. Performance data presented in this report were obtained from Reference 2.

A. HEAD FLOW (H-Q) RESULTS

The head-flow (H-Q) performance map of the inducer/impeller is shown in Figure 16. Data points were obtained at 25, 40, and 75% of design speed (Test 13) and at a wide operating flow range (59 to 170% design Q/N). Only stable operation was encountered, and the slope of the H-Q curve remained negative throughout the entire flow range tested. The predicted performance

Figure 16. Inducer/Impeller Head/Flow Performance

Figure 17. Overall Head/Flow Performance

TABLE 6
QUOTED INDUCER PUMP PERFORMANCE AT DESIGN Q/N
BASED ON WATER TEST DATA

Design Speed (%)	Speed (rpm)	Inlet Flow Rate (gpm)	Inducer/ Impeller Developed Head (ft)	Overall Developed Head* (ft)	Critical NPSH (ft)
25	832	708	38	36	0.5
40	1332	1134	95	92	1.3
75	2497	2126	335	317	4.7
100	3329	2834	596	563	8.4

*Inlet to volute discharge

curves are also shown, and it can be seen that the H-Q pump performance exceeded the predicted performance at all test conditions. The overall (inducer inlet to volute discharge pipe) H-Q data are shown in Figure 17. Again, only stable operation was encountered, and the slope of the H-Q curve remained negative throughout the entire flow range. Figures 18 and 19 show the H/N^2 vs Q/N data based on Figures 16 and 17, respectively. Some data scatter occurs at the high flow end; this is attributed to additional leakage through the pump internal clearances at the higher pump speeds.

B. CAVITATION RESULTS

Results of the cavitation tests are shown in Figure 20. Those tests (Tests 15 and 16) were conducted at constant speed and at flow rates of about 111, 86, 106, and 99% design Q/N. These tests were conducted using the constant throttle valve procedure discussed in Reference 1. The critical NPSH was obtained when the head decreased to 97% of the noncavitating head. These critical (required) net positive suction head (NPSH) points are shown in

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Figure 18. Inducer/Impeller Head/Flow Performance

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Figure 19. Overall Head/Flow Performance

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Figure 20. NPSH Test Data Summary
(all data corrected to 75% rpm)

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Figure 21. Critical NPSH at 75% Speed vs Q/N

Figure 21. Based on the average curve through these points, the actual suction specific speed capability (S_s capability) at a function of flow rate was obtained by

$$S_s \text{ capability} = \frac{N Q_1^{1/2}}{(\text{critical NPSH})^{3/4}}$$

where:

N = speed, rpm

Q_1 = inlet flow rate, gpm

These S_s capability values are shown in Figure 22. The data were also scaled to the 100% speed, using the pump affinity laws (flow rate proportional to speed, and NPSH proportional to speed-squared), and are shown in Figure 23. At the design point, the critical NPSH was 8.4 ft (predicted minimum critical NPSH was 9 ft).

Figure 22. Critical Suction Specific Speed Performance

Figure 23. Critical NPSH Scaled to 100% Speed

C. OPERATIONAL TEST RESULTS

The operational test (Test 17) was conducted on April 11, 1977, and consisted of operating the inducer pump at an NPSH margin of between 70 to 100% (NPSH = 8.6 to 10.12 ft) for 8 h, 23 min at 75% design speed (2497 rpm) and at 100% design Q/N (0.85 gallons/rev). The approximate total duration of pump operation at an NPSH margin of 100% or less, at 75% design speed, was 10 h. The total pump operating duration for this test program at HTF was approximately 38 h, 39 min. Part of the pump duration was conducted without the digital data acquisition system in operation and was, therefore, recorded manually. Upon disassembly of the inducer pump, a visual examination was conducted on the inducer, impeller, diffuser, and internal stationary pump parts. No visible cavitation damage (erosion) could be detected. The post-test appearance of the hardware was, to the human eye, the same as the pre-test appearance.

D. INDUCER/IMPELLER EFFICIENCY RESULTS

Efficiency was obtained from the H-Q test at 75% speed (Test 13). Figure 24 shows the inducer/impeller efficiency as a function of inlet flow rate. The data were based on inlet flow rate and developed head from the pump inlet to impeller discharge, and were corrected for the oil seal and oil bearing (3 ea) parasitic losses. The 5.58 hp loss, shown in Reference 2, was obtained by calculating the bearing and seal power dissipated into the lubrication oil. The following describes this calculation:

$$\begin{aligned} \text{hp}_{\text{Para}} &= \text{Parasitic Losses, hp} \\ &= G C_p (t_b - t_a) \frac{778.2}{550}, \text{ hp} \end{aligned}$$

where:

G = oil mass flow rate, lb/sec

$$= \frac{Q_T \rho}{60(7.4805)} = \frac{Q_T(0.876)(62.43)}{448.83}$$

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Figure 24. AI Pump Water Test Efficiency

$$C_p = \text{oil specific heat at constant pressure, } \frac{\text{Btu}}{\text{lb}^\circ \text{F}}$$

$$= 0.443 + 0.009 (t_c - 15)$$

$$= 0.443 + 0.0009 \left\{ \left[\frac{5}{9} (t_f - 32) \right] - 15 \right\}$$

$$t_b = \text{Outlet oil temperature, } ^\circ \text{F}$$

$$t_a = \text{Inlet oil temperature, } ^\circ \text{F}$$

$$t_f = \text{Average oil temperature, } ^\circ \text{F}$$

$$Q_T = \text{Total oil flow rate, gpm}$$

TABLE 7
PARASITIC LOSS DATA AND RESULTS
(Test No. 16)

Test Point	Time (h)	Total Oil Flow Rate (gpm)	Suction Water Temperature (°F)	Discharge Water Temperature (°F)	Pump Inlet Oil Temperature (°F)	Pump Outlet Oil Temperature (°F)	Delta Temperature (° F)	hp Loss
1	11:00 a.m.	17.8	75.1	78.3	95.3	99.0	3.8	5.38
2	12:00 p.m.	17.9	82.4	85.3	94.6	99.5	4.8	7.03
3	1:00 p.m.	17.9	88.9	88.9	95.7	99.4	3.8	5.41
4	1:30 p.m.	17.9	90.7	92.1	95.1	99.4	4.3	6.12
5	2:00 p.m.	17.9	94.4	96.0	96.0	99.9	3.9	5.58
6	2:30 p.m.	17.9	98.1	96.2	92.4	96.8	4.4	6.24
7	3:00 p.m.	17.9	98.2	95.9	92.1	96.0	3.9	5.53
8	3:30 p.m.	18.0	100.4	97.9	90.8	96.0	5.2	7.41
9	4:00 p.m.	17.91	101.7	99.4	93.5	97.8	4.3	6.11
10	4:30 p.m.	18.15	104.4	100.1	94.4	98.6	4.2	6.05
11	5:00 p.m.	18.19	106.5	101.4	92.2	96.3	4.0	5.76
12	5:24 p.m.	18.18	108.2	102.3	90.8	96.0	5.2	7.48

Therefore:

$$\begin{aligned} \text{hp}_{\text{Para}} &= 0.122 Q_T \left(0.443 + 0.0009 \left\{ \left[\frac{5}{9} (t_f - 32) \right] - 15 \right\} \right) (t_b - t_a) \frac{778.2}{550} \\ &= 0.172 Q_T \left(0.443 + 0.0009 \left\{ \left[\frac{5}{9} (t_f - 32) \right] - 15 \right\} \right) (t_b - t_a) \end{aligned}$$

Data were recorded during the endurance test and are listed in Table 7. At Test point 5, the pump discharge water and inlet oil temperatures were equal (96°F) and heat transfer between the pumped fluid and the bearing oil was minimized. The calculated horsepower at this point was 5.58 hp which was subtracted from the brake horsepower (Figure 25) as calculated from torque and speed. The fluid horsepower (Figure 26), as based on inlet flow rate and inducer/impeller head, was divided by this corrected brake horsepower to obtain the efficiency shown in Figure 24. The following efficiency equation was used.

$$\text{EC1} = \frac{\text{FC1}}{\text{BC1} - 5.58}$$

where:

EC1 = inducer/impeller efficiency

FC1 = fluid horsepower based on inlet flow rate and inducer/
impeller head

BC1 = Bhp input based on torque and speed

Figure 25. AI Pump Water Test Brake Horsepower

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Figure 26. AI Pump Water Test Fluid Horsepower

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VI. BLADING SURFACE INSPECTION RESULTS

The blading of the inducer and impeller were photographed prior to and following water testing. Macro-photographs were made, and surface replicas at prescribed stations were taken. Pre-test surface replicas were taken at 62 stations on the inducer, and at 56 stations on the impeller. Post-test visual inspection of the blading surfaces revealed that the surface machining marks were virtually unaltered, as indicated in Figure 27. Therefore, replicas were limited to 4 reference stations on the inducer; this saved considerable time in the pump inspection process.

The basic visual appearance of the inducer blade surface is shown in Figure 27(A). This is a post-test photograph, and the radial machining marks on the blade are clearly shown. (The darkened area is due to lighting conditions of the photo.) In Figure 27(B), photos of the acetate molds taken at the same station of the inducer (the leading edge OD) are shown, and in Figure 27(C) photos of the carbon chrome replicas taken from specific areas of the molds are presented. In Figure 27(D) the electron microscope photos of these at approximately magnification 4,000 are shown.

These large magnification photos show the surface detail of the inducer blade. They should be compared by examining "flat-looking" section of the photo and inspecting for the density of surface defects ("pits" or "craters"). As is seen from Figure 27(D), the density is unaltered. The presence of any cavitation erosion, or onset of such, would be indicated by an abrupt increase in pit formation.

Exact matching of the area was not made at this magnification, nor was it considered necessary under the observed conditions. It was thus concluded that no general or microscopic damage to the blading surfaces was indicated by the inspection that was performed.

a. Inducer, $\sim 0.5x$, post-test only; machining marks give same appearance as pre-test conditions

Pre-test

Post-test

b. Acetate molds, $\sim 10x$

Pre-test

Post-test

c. Carbon chrome replicas taken from molds, $\sim 30x$

Pre-test

Post-test

d. Carbon chrome replicas, $\sim 4000x$

Figure 27. Inducer Blading Surface Condition
(Typical comparative photos indicating
virtually no change in
surface condition)

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VII. VIBRATION TEST RESULTS

A. GENERAL

Signature analysis measurements were recorded at the Hydraulic Test Facility on the inducer pump from January 28 to April 7, 1977. These measurements were performed as part of a program to monitor vibration characteristics of the pump in water and in sodium. The data and observations made during the water testing are presented in the form of spectral analysis plots. An evaluation of the results is presented.

(NOTE: The analysis and conclusions derived from the spectral plots developed as part of this test depend upon the assignments of various causes and effects. Direct calculations are dependent upon the source of these assignments. The pump characteristic frequency derived from the rpm is a form of direct calculation. The cause and effect assignment requires analytical and test data to assure accurate phenomena interpretation. The tests reported herein can, however, indicate the existence of a resonance signal, separate it from the background, and indicate changes in the amplitude.)

The main purposes of this instrumentation were to monitor the pump's fundamental shaft vibration, determine if the vibration levels necessitated action in terms of test shutdown based on the limit of 0.1 g as established by Reference 1, and to record the analog data from all channels on wide band magnetic tape for further analysis. Four piezoelectric accelerometers were used to detect the vibration. Figure 28 defines the sensor locations and sensitive axes, and Table 8 contains sensor information.

No abnormal characteristics were noted during the testing or from an analysis of the spectral plots.

The vibration limit criteria of 0.1 g's rms, as established by Reference 1, was not exceeded at the fundamental pump shaft frequency during the water testing. The largest vibration recorded was 0.024 g's rms or a factor of 4.2 under the vibration limit criteria.

- NOTES: 1. SENSITIVE AXIS OF Z1 AND Z4 90° TO SENSITIVE AXIS OF Z2 AND Z3
2. Z3 AND Z4 ATTACHED WITH MOUNTING BLOCKS
3. SEE APPENDIX I

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Figure 28. Vibration Sensor Locations for Inducer Pump

TABLE 8
VIBRATION SENSOR LIST FOR INDUCER PUMP

Designation	Type	Manufacturer	Model	Serial Number	Sensitivity
Z1	Accelerometer	Endevco	2271A	CU55	11.5%/g at 100 Hz
Z2	Accelerometer	Endevco	2271A	CM44	11.5%/g at 100 Hz
Z3	Accelerometer	Endevco	2276	BD65	10.35%/g at 100 Hz
Z4	Accelerometer	Endevco	2276	B629	10.7%/g at 100 Hz

B. DATA ACQUISITION

Data acquisition commenced, with the checkout tests, on January 28, 1977, and was completed on April 11, 1977, with the completion of the eight-hour test. Tape recordings were made during this period up to the completion of the final cavitation test on April 7, 1977. The charge outputs, from sensors listed on Table 8, were amplified and scaled by Endevco 2735 charge amplifiers. Other equipment used included a B&H 4040 14-channel FM tape recorder and a EMR 1510 spectrum analyzer. Recording equipment was calibrated for recording at 30 ips using a center frequency of 108 kc with the 40% deviation corresponding to 5.0 V rms.

The pump shaft vibration in g's peak-to-peak was recorded on HTF Data Sheet 3, per the LMEC Test Procedure. The results, based on averaged spectra, were measured on the spectrum analyzer in db down from a reference. Appendix I contains the HTF Data Sheets, which are ordered by the test number as described in Section IV of this report.

C. DATA REDUCTION

Frequency domain data reduction was performed by the EMR 256-line spectrum analyzer. During the tests, the fundamental pump shaft frequency vibration level was recorded directly from averaged spectra. In some cases, spectral plots were made on the x-y plotter from the averaged spectral data. These plots are presented in Appendix II with the decibel scale vs frequency. Sixteen sequential samples of data were averaged prior to plotting. Scale factors are provided on each plot to relate the db level to the rms amplitude of vibration.

D. ANALYSIS AND RESULTS

The results are obtained from the frequency domain measurements made during the tests listed below.

1. Checkout Tests

Checkout testing was performed between January 28 and February 2, 1977. The location of all accelerometers for the checkout tests are identified on Figure 28. All vibration levels were under the vibration limit criteria of 0.2828 g's peak-to-peak. Levels for each test are shown in Tables I-1 and I-2 in Appendix I.

The highest vibration level recorded during checkout test 2A was 0.067 g's peak-peak at 2250 rpm. A spectral plot of Test 2A is shown in Figure II-1 in Appendix II. This level represents a safety factor of 4.2 under the vibration limit criteria. The component at 76 Hz indicates a slight misalignment between the right angle gear drive output shaft and the pump shaft.

2. Head Flow Tests

Head flow tests were performed February 4 to February 8, 1977 and on March 30, 1977. The worst case vibration was recorded on the center flange (Position D) at 2510 rpm. This level of 0.0443 g's peak-to-peak is a factor of 6.4 under the vibration limit criteria. Vibration data for the head flow tests is shown in Tables I-3, I-4, I-5, and I-11 of Appendix I.

3. Cavitation Tests

Cavitation tests were conducted from February 10 to April 7, 1977. Since the test loop was modified during the cavitation tests and an accelerometer (Z4) was moved, this analysis will be presented in chronological order.

February 10 to February 16

These tests were performed prior to any test loop modifications. Accelerometer locations are given on Figure 28. The fundamental pump shaft vibration was well within the vibration limit criteria at 0.040 g's peak-to-peak or a safety factor of 7, as shown in Tables I-6, I-7, and I-8 of Appendix I.

March 4 through 7, 1977

Two changes were made prior to testing:

- (1) A viewing section was added at the inducer inlet
- (2) Because of (1) above, transducer Z4 was relocated 12 ft upstream on the inlet pipe as shown in Figure 29.

Fundamental pump shaft vibration data for this testing was below the vibration limit criteria, as shown on Tables I-9 and I-10 in Appendix I.

March 30 through April 7

Prior to these tests, a deaeration tank was added to the test loop. The largest fundamental pump shaft vibration recorded was 0.067 g's peak-peak or a factor of 4.2 under the vibration limit criteria.

Spectral plots taken on April 7, 1977, are presented as Figures II-2 through II-23 in Appendix II.

4. Eight-Hour Test

The four spectral plots for Test 17 (Figures II-24 through II-27 in Appendix II) indicate the existence of the fundamental pump shaft frequency at 42 Hz and a second harmonic component at 84 Hz. The 84 Hz component is due to a slight misalignment between the right angle gear drive output shaft and the pump's shaft. The 84 Hz amplitude level is acceptable and would not induce wear of the pump's upper bearing.

Fundamental pump shaft vibration ranged from 0.0089 to 0.031 g's peak-to-peak, considerably below the vibration limit criteria of 0.2828 g's peak-to-peak.

Figure II-26 indicates a 36 Hz component at the pump inlet accelerometer, Z3. This component, a subharmonic of a 72 Hz vibration, is caused by the combination of the 30 Hz motor fundamental frequency and the 42 Hz pump shaft frequency in the right angle gear drive unit. In a nonlinear mechanical mechanism such as the right angle gear drive, the combination of two frequencies results in sums and differences of the input frequencies. The 72 Hz component represents the sum of the 30 Hz and 42 Hz components and is a driving force. The system's response to the driving force is the subharmonic at 36 Hz. This component does not reflect pump shaft vibration.

Figure 29. Relocation of Inlet Vibration Transducer Z_4

Data on Figure II-27 is of little value with regard to pump conditions, since the accelerometer, Z4, was relocated 12 ft upstream on the inlet line with the sensitive axis parallel to the pump shaft. Peaks in the spectra are associated with structural and inlet pipe resonances.

REFERENCES

1. Hoshide, R. K., "Water Testing of the Subscale Inducer Test Article in the Hydraulic Test Facility," Report N147RFT530-001, Atomics International, Canoga Park, California, October 6, 1976
2. Whitten, S. D., "Atomics International Inducer Pump Water Test at HTF-Interim Report," Document R-063E-C01-TI006, Liquid Metals Engineering Center, Canoga Park, California, June 1, 1977
3. Annual Technical Progress Report, Inducer Pump Program, Government Fiscal Year 1976 and 1976T, AI-ERDA-13185, November 15, 1976

APPENDICES

APPENDIX I. VIBRATION DATA – HTF DATA SHEET 3

APPENDIX II. SPECTRAL PLOTS

APPENDIX I

VIBRATION DATA
HTF DATA SHEET 3

TABLE I-1
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number _____ Test No. 2, Checkout _____

Shaft rpm/Hz	690/11.5	829/13.8	1050/17.5	1290/21.5	1540/25.6
Date	1-31-77	1-31-77	1-31-77	1-31-77	1-31-77
Time	16:00	16:11	16:24	16:34	16:45
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0014	0.00283	0.00238	0.0123	0.0168
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.00178	0.00428	0.00332	0.0048	0.0088
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.00159	0.00178	0.00289	0.0094	0.0078
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.00152	0.00225	0.0039	0.0084	0.0059
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-1
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 2, Checkout (Continued)

Shaft rpm/Hz	1770/29.5				
Date	1-31-77				
Time	16:54				
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0092				
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0204				
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0081				
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0056				
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-2

HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number _____ Test No. 2A, Checkout _____

Shaft rpm/Hz	604/10	900/15	1170/19.5	1430/238	1985/33.6
Date	2-2-77	2-2-77	2-2-77	2-2-77	2-2-77
Time	12:09	12:20	12:24	12:28	12:40
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0020	0.0024	0.0050	0.0195	No data
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0022	0.0037	0.0023	0.0073	No data
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0014	0.0028	0.0118	No data	0.0168
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0030	0.0034	0.0070	No data	0.0125
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-2

HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 2A, Checkout (Continued)

Shaft rpm/Hz	2250/38	2523/42	2523/42		
Date	2-2-77	2-2-77	2-2-77		
Time	12:58	14:00	14:10		
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.004	0.0078	0.0078		
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0062	0.0151	0.0146		
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0386	0.0626	0.0626		
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0670	0.0515	0.0497		
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I- 3
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 3, 25% Speed H-Q

Shaft rpm/Hz	670/11.1	835/14			
Date	2-4-77	2-4-77			
Time	15:20	15:30			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0015	0.0015			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0012	0.0028			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.00135	0.00155			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0016	0.0016			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-4
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 4, 40% Speed H-Q

Shaft rpm/Hz	640/10.6	1347/22.4			
Date	2-7-77	2-7-77			
Time	13:03	13:18			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.00122	0.0127			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.00176	0.0051			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.00165	0.0110			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0017	0.0072			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-5
HTF DATA SHEET 3 – VIBRATION DATA

Procedure Number _____ Test No. 5, 75% Speed H-Q _____

Shaft rpm/Hz	692/11.5	2510/42			
Date	2-8-77	2-8-77			
Time	13:27	13:55			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.00139	0.0025			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0014	0.0131			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0015	0.0222			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0016	0.0443			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-6
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 6, 100% Q/N Cavitation

Shaft rpm/Hz	2523/42	2515/42			
Date	2-10-77	2-10-77			
Time	13:29	13:47			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0091	0.0063			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0145	0.0360			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0296	0.0180			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0404	0.0313			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-7
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 7, 109% Q/N Cavitation

Shaft rpm/Hz	2507/42	2497/41.6			
Date	2-14-77	2-14-77			
Time	14:25	15:00			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0048	0.0059			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0084	0.0123			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0220	0.0195			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0048	0.0025			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-8
HTF DATA SHEET 3 – VIBRATION DATA

Procedure Number Test No. 8, 125%, 140% and 90% Q/N Cavitation

Shaft rpm/Hz	2005/33.4	2018/33.5	2005/33.4		
Date	2-16-77	2-16-77	2-16-77		
Time	14:27	14:58	15:23		
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0033	0.0084	0.0094		
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0029	0.0063	0.0078		
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0091	0.0145	0.0181		
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0113	0.0245	0.0151		
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-9
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 10, 100% Q/N Cavitation

Shaft rpm/Hz	2502/41.8	2499/41.6			
Date	3-4-77	3-4-77			
Time	14:21	15:17			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0195	0.0678			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0222	0.0625			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0095	0.0137			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0090	0.0092			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

NOTE: V-1 and V-2 Position changed due to insert
V-2 New position is now in same axis $\approx$ 1 ft below previous location
V-1 New position is now midway between elbows on inlet, sensitive axis in vertical plane
V-1 and V-2 Shaft vibration data not comparable to previous data

TABLE I-10
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 11, 100% Q/N Cavitation

Shaft rpm/Hz	2486/41.4	2473/41.2			
Date	3-7-77	3-7-77			
Time	15:05	3:24			
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0443	0.0404			
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0514	0.0443			
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0195	0.0625			
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0048	0.0222			
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

TABLE I-11
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 13, 25%, 40%, and 75% H-Q

Shaft rpm/Hz	619/10.3	2516/42	2495/41.6		
Date	3-30-77	3-30-77	3-30-77		
Time	9:47	10:11	10:21		
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.0013	0.013	0.010		
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.0023	0.018	0.012		
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.0017	0.067	0.044		
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.0025	0.050	0.022		
Procedure Step					

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

NOTE: Sensor locations same except for Ch-6, now motor (radial)
Sensor sensitive axis same

TABLE I-12
HTF DATA SHEET 3 - VIBRATION DATA

Procedure Number Test No. 14, 100% Q/N Cavitation

Shaft rpm/Hz	2496/41.6				
Date	3-31-77				
Time	10:20				
Tape Recorder (Ch-5) V-1 Pump Inlet Position A	0.014				
Tape Recorder (Ch-4) V-2 Pump Inlet Position B	0.019				
Tape Recorder (Ch-2) V-3 Center Flange Position C	0.051				
Tape Recorder (Ch-1) V-4 Center Flange Position D	0.027				
Procedure Step	Cavitation Test No. 1				

Vibration data entries shall be peak-to-peak amplitudes of acceleration in "g" at the pump rotational frequency.

NOTE: No cavitation data Test No. 2, intercom died

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APPENDIX II

SPECTRAL PLOTS

Figure II-1. Spectral Plot,
Test No. 2A, Checkout

Z1: 2-2-77 13:02

rpm: 2250

0 db = 1 g rms

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Figure II-2. Test No. 16, 90% Q/N
Cav., 28 ft, NPSH

Z1: 4-7-77

rpm: 2590

0 db = 3 g

HEAD: 29 ft

Q = 90%

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Figure II-3. Test No. 16, 90% Q/N
Cav., NPSH = 9.4 ft

Z1: 4-7-77

rpm: 2590

0 db: 3 g

HEAD: 9.4 ft

Q = 90%

Figure II-5. Test No. 16, 90% Q/N
Cav., NPSH = 29 ft

Z1: 4-7-77

rpm: 2590

0 db = 3 g

HEAD: 29 ft

Q = 90%

Figure II-6. Test No. 16, 90% Q/N
Cav., NPSH = 8.3 ft

Z1: 4-7-77

rpm: 2590

0 db = 3 g

HEAD: 8.3 ft

Q = 90%

Figure II-7. Test No. 16, 70% Q/N
Cav., NPSH = 5.1 ft

Z1: 4-7-77

rpm: 2590

0 db = 3 g

HEAD: 5.1 ft

Q = 90%

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Figure II-9. Test No.16, 106% Q/N²
Cav., NPSH = 26 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 26 ft

Q = 106%

Figure II-11. Test No. 16, 106% Q/N²
Cav., NPSH = 5.4 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 5.4 ft

Q = 106%

Figure II-13. Test No. 16, 106% Q/N²
Cav., NPSH = 3.4 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 3.4 ft

Q = 106%

Figure II-14. Test No. 16, 106%
Q/N Cav., NPSH =
10.2 ft

Z 3: 4-7-77

rpm: 2581

0 db $\approx$ 3 g

HEAD: 10.2 ft

Q = 106%

Figure II-15. Test No. 16 106% Q/N
Cav., NPSH = 6.5 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 6.5 ft

Q = 106%

Figure II-16. Test No. 16, 106% Q/N
Cav., NPSH = 4.9 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 4.9 ft

Q = 104%

Figure II-18. Test No. 16, 100% Q/N
Cav., NPSH = 16 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 16 ft

Q = 100%

Figure II-19. Test No.16, 100% Q/N³
Cav., NPSH = 6 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 6 ft

Q ≈ 100%

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Figure II-20. Test No. 16, 100% Q/N³
Cav., NPSH = 25 ft

Z 3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 25 ft

Q = 100%

Figure II-21. Test No. 16, 100% Q/N³
Cav., NPSH = 14.5 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 14.5 ft

Q = 100%

Figure II-22. Test No.16, 100% Q/N³
Cav., NPSH = 10 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 10 ft

Q = 100%

Figure II-23. Test No.16, 100% Q/N³
Cav., NPSH = 4.8 ft

Z3: 4-7-77

rpm: 2581

0 db = 3 g

HEAD: 4.8 ft

Q = 100%

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Figure II-25. Test No.17, 8 h Duration, Z2

Z2: 4-11-77

rpm: 2542

0 db = 3 g rms

Figure II-26. Test No. 17, 8 h
Duration, Z3

Z3: 4-11-77

rpm: 2542

0 db = 3 g rms

Figure II-27. Test No. 17, 8 h
Duration, Z4

Z4: 4-11-77

rpm: 2542

0 db = 3 g rms