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Intermediate - Size Inducer Pump (ISIP-II) Test Program In SPTF Final Report

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Energy Technology Engineering Center

Operated for the U.S. Department of Energy
by Energy Systems Group, Rockwell International

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ABSTRACT

This report presents the results of a test program of the Intermediate-Size Inducer Pump II (ISIP-II).

The program objective was to develop LMFBR technology. This was accomplished by testing an intermediate-size inducer pump in sodium. The FFTF primary pump was used as the basic test article. The FFTF pump was modified to accommodate an inducer-impeller combination and diffuser.

The overall test program includes pump assembly, installation, testing, removal from the test loop, disassembly, and final inspection of the entire pump. This report covers only the pump assembly, installation, and testing aspects of the program. The decision was made to leave the test article installed in the pump tank for a period of ∿2 months after testing was completed because of schedule interference at the Component Handling and Cleaning Facility (CHCF). When the schedule permits, the test article will be removed from the pump tank, cleaned of sodium in the alcohol cleaning vessel, disassembled, and examined. An inspection report will be issued at a later date.

Testing included: pump checkout tests; head, flow, and power characterizations; operation at design and two-loop resistances; and operation over a range of sodium temperatures. A cavitation test was performed to determine the critical net positive suction head (NPSH). A 48-h endurance run at an elevated sodium temperature was performed. There was also an endurance run at 155% of the critical NPSH at design temperature.

Testing took place at the Energy Technology Engineering Center (ETEC). Test-article assembly was performed at CHCF and sodium testing at the Sodium Pump Test Facility (SPTF).

AI-ESG monitored test-article assembly and testing at ETEC.

I. INTRODUCTION

The ISIP-II sodium pump was tested at the Energy Technology Engineering Center (ETEC). Installation of the pump into the pump tank began February 19, 1981. Sodium testing was completed and sodium drained from the system on August 30, 1981.

The purpose of this test program was to demonstrate the applicability of the pump inducer concept to large, high-temperature sodium pumps.

The test program included steady-state performance tests over wide ranges of speed, flow, and sodium temperature. Also included was a cavitation test to establish the critical NPSH. Endurance tests at 155% of the critical NPSH at 950°F and at an NPSH of 60 ft at 1050°F were also performed.

The test article was a modified FFTF primary pump. The modification consisted of replacing the standard impeller with an integral inducer-impeller combination. Other components to adapt the new impeller assembly to the existing Fast Flux Test Facility (FFTF) pump were included.

The ISIP-II pump was tested at the Sodium Pump Test Facility (SPTF) during FY 1981. An unmodified FFTF pump was tested during 1977 at the same ETEC facility.

The Intermediate-Size Inducer Pump Program is an extension of the technology development that was initiated under subscale inducer pump development for the Department of Energy. The subscale inducer pump development task utilized the advanced hydrodynamic analysis techniques developed at Rockwell International. The ISIP-II tests extended and qualified sodium inducer technology to the 14,500-gpm (0.915-m^3/s) range.

The ISIP hydrodynamic components — inducer, impeller, diffuser, and other parts required to install the ISIP hydrodynamic components in the FFTF primary pump — were structurally designed to meet the intent of the requirements for internal components for the FFTF primary pump as given in the FFTF Pump Specification HWS-1551, "Specification LMFBR Low Capacity Prototype Pump and FFTF Primary Pump," Revision 1, dated January 11, 1974.

II. SUMMARY

All objectives of demonstrating pump performance as outlined in the Request for Test were met within schedule. The following objectives were successfully accomplished:

1) To characterize pump head, flow, power, and speed relationships in the operating region between design and two-loop flow impedance over a range of sodium temperatures
2) To determine the pump's critical NPSH
3) To extend pump operation at 1050°F (566°C)
4) To extend pump operation at a reduced NPSH.

The test program was extended 2 weeks beyond the originally scheduled shutdown to permit additional run duration at reduced NPSH for the endurance run.

Performance tests, which consisted of speed scans at two flow resistances and two flow scans, were performed over a range of sodium temperatures from 700°F (371°C) to 1050°F (566°C). The developed head was determined to be significantly higher than that achieved during the FFTF test program. The developed head at a 1110-rpm pump speed and a flow of 14,500 gpm (0.9148 m^3/s) was 562 ft (171.3 m). This is slightly higher than the Rocketdyne prediction of 546 ft (166.4 m) for these operating conditions.

The critical NPSH was established during a cavitation test. The NPSH was reduced to 11.3 ft (3.44 m) to achieve a head reduction of 2.1%. The cavitation test was terminated before the targeted 3.0% head drop was reached because of what was perceived to be excessive cavitation in the facility pressure reduction device. The design requirement of 12.8 ft NPSH (maximum) at the design flow was successfully met and exceeded by a 12% margin.

A 48-h endurance run was successfully performed at 1050°F (566°C) to qualify the pump shaft for use in FFTF.

An endurance run of 941-h duration was performed at an NPSH of 29 ft (8.84 m). This NPSH was 155% of the established critical NPSH. The desired run duration of 2000 h was not achieved because of schedule interference with the next pump test program for SPTF. There were no technical reasons for limiting the endurance test program.

III. CONCLUSIONS

Test results verified that the inducer pump design objectives of critical NPSH, speed, flow, and head were achieved. A critical NPSH value of 11.3 ft was measured, surpassing the target performance value of 12.8 ft, at design flow and speed (14,500 gpm and 1110 rpm) with 950°F sodium. The developed head was 562 ft, exceeding the design requirement of 500 ft. The higher-than-required head was an anticipated result which could be adjusted to a lower value by reducing impeller diameter. Despite the high head, power requirements were still well within the drive motor rating.

No adverse operating characteristics were noted over the range of test conditions. Sodium bearing performance with the inducer-impeller combination appeared stable, with adequate film thickness and no evidence of excessive radial thrust or excessive unbalanced loads. The final performance criterion — no visual evidence of cavitation damage — will be evaluated after pump cleaning and disassembly.

IV. PROGRAM OBJECTIVE

The objective of the Intermediate-Size Inducer Pump Program II (ISIP-II) was to test an inducer and impeller, designed and fabricated under the original ISIP program. Testing was performed in the Sodium Pump Test Facility at the Energy Technology Engineering Center. The FFTF P-1 primary pump was used as the test vehicle. The pump was tested in sodium to measure its suction performance at a steady-state temperature of 950°F. This is representative of the temperature being used in design of large-scale breeder reactors.

V. DESCRIPTION OF TEST ARTICLE

The intermediate-size inducer pump is an FFTF primary pump modified by replacing the original impeller with an inducer, a new impeller, and other components needed to adapt the existing pump for use with the new pump rotating elements.

Outwardly, the intermediate-size inducer pump is identical to the FFTF prototype pump previously tested at ETEC. Physical interfaces are identical, and functional interfaces remain basically unchanged from the original FFTF configuration.

A. TEST ARTICLE GENERAL DESCRIPTION

The test article is a vertical, free-surface, centrifugal pump designed to deliver 14,500 gpm (0.9148 m^3/s) of 1050^oF (565.6^oC) sodium at a differential head of 500 ft (152.3 m) The actual head produced by the pump was 562 ft (171.3 m) because the impeller had not been trimmed to achieve the design head.

Included with the pump are: (1) a vertical wound-rotor drive motor, (2) a liquid rheostat to control motor speed, (3) an oil lubrication system, (4) two control cabinets, and (5) various pump-mounted instruments.

The hydraulic end of the pump (impeller, inducer, diffuser, sodium bearing, thermal shield, and radiation shield) is enclosed in a Type 304 stainless steel tank $\sim$35 ft (10.7 m) long and 7 ft (2.1 m) in diameter. The internal parts are also stainless steel. The upper bearings and shaft seal are oil lubricated; the lower bearing is a sodium-lubricated hydrostatic bearing.

Figure 1 is a simplified illustration of the general arrangement of major components in the pump. Inlet suction flow enters the pump hydraulic assembly via the internal suction elbow (located in direct line with the suction nozzle), passes through the elbow length, enters the inducer, and is directed to the

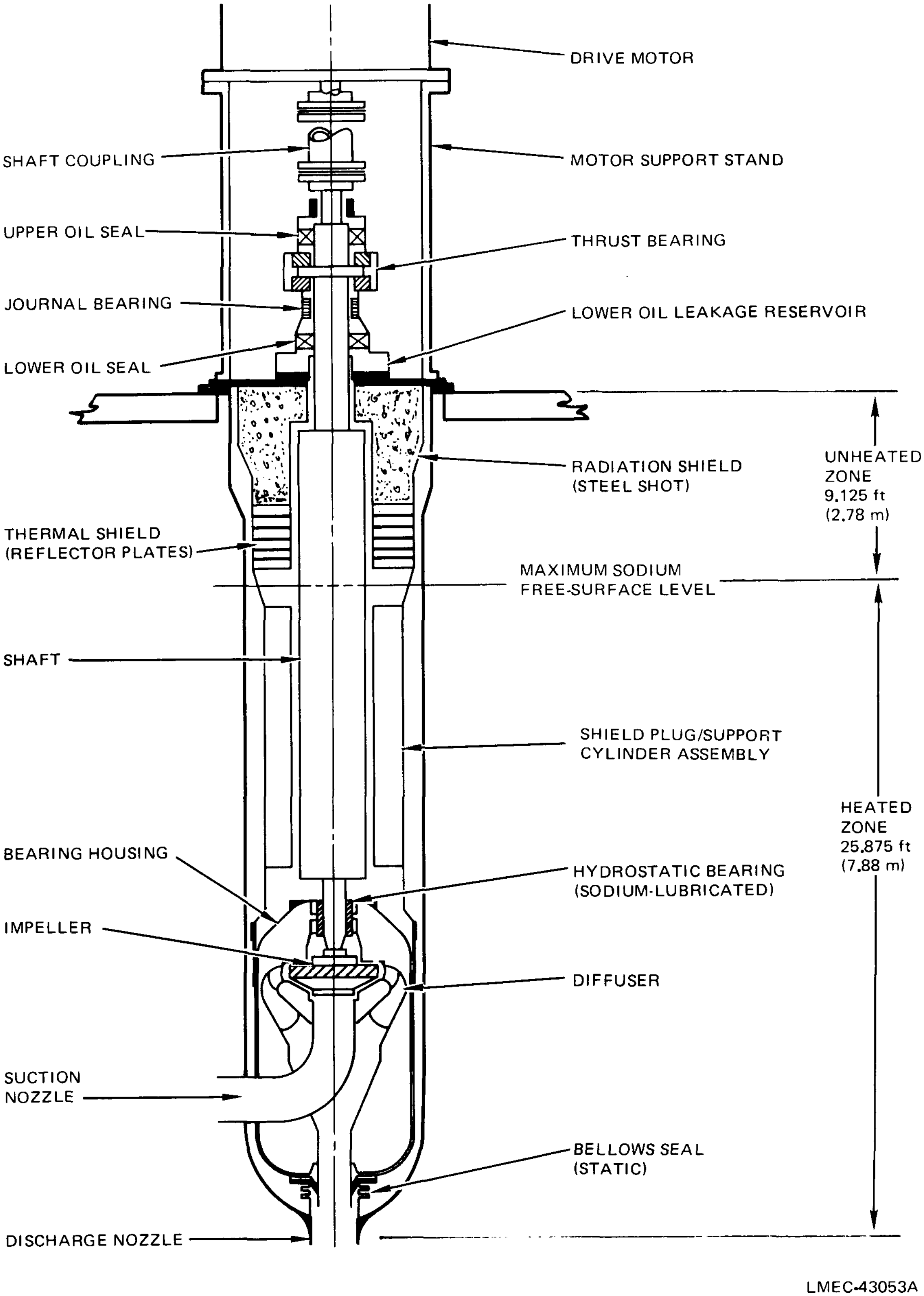

Figure 1. ISIP-II Sodium Pump — Simplified Illustration

impeller eye traveling in an upward direction. The impeller increases the flow velocity. This flow is discharged radially from the impeller and enters the diffuser and then the turning vane that converts velocity head to pressure head and redirects the flow from a radial direction to a downward direction. The high-pressure fluid then moves downward along the hydraulic discharge passage and exits from the pump through the discharge nozzle.

Within the hydraulic assembly, a secondary flow pattern exists in conjunction with the main flow described above. At the extreme bottom end of the diffuser/turning vane assembly, ∿0.3% of the main flow is directed into the cavity formed by the pressure casing. This fluid is thoroughly mixed before flowing upward between the casing and the diffuser/turning vane assembly walls into the bearing supply reservoir portion of the bearing support housing. From this reservoir, flow is injected through control orifices into the inner pressure pockets of the sodium-lubricated hydrostatic bearing. It is by means of this secondary high-pressure flow that the load-carrying capabilities of the bearing are developed and lateral support to the pump rotor is provided.

A summary of general data for the pump and drive motor is presented in Table 1. A brief description of the pump components is given in the following paragraphs. For a more detailed description of the pump and motor, refer to the Westinghouse Operation and Maintenance Manual.[1,2]

B. DESCRIPTION OF PUMP COMPONENTS

The pump consists of 16 general areas: the tank, tank bolting ring, pump shaft, shield plug/support cylinder assembly, static hydraulics, impeller-inducer assembly, seals, oil bearings, bearing support and hydrostatic bearing, disconnect bellows, motor support stand, coupling, drive motor, pony motor, instrumentation, and an oil circulation system. A description of each of these areas follows.

TABLE 1

SUMMARY OF GENERAL PUMP DATA

General	
Pump type	Centrifugal, free surface, single suction, single stage, vertical shaft with shaft seal, variable speed
Shaft seals	Oil-lubricated, rubbing face, controlled leakage
Sodium bearing	12 in. x 12 in. hydrostatic (0.3048 x 0.3048 m)
Design temperature	$1050^{o}F$ ($565.6^{o}C$)
Design Pressure:	
Suction	120 psig (827.4 kPa)
Discharge	225 psig (1551.3 kPa)
Hydraulics at Design Point	
Flow	14,500 gpm (0.9148 m^3/s)
Head	500 ft (152.3 m)
Speed	1110 rpm
Size and Weight Data	
Overall pump length	56 ft (17.07 m)
Pump tank length	35 ft (25.91 m)
Pump tank OD	80 in. (2.032 m)
Total weight (operating)	165 tons (1.497×10^5 kg)
Weight of removable internals	82 tons (7.439×10^4 kg)
Driver Data	
Type	Wound rotor induction, air-cooled, with pony motor
Rating	2500 hp (1865 KAV)
Speed control	Liquid rheostat
Speed range	550 to 1132 rpm

1. Pump Tank

The Type 304 stainless steel pump tank is of cylindrical construction with a dished head at the lower end. The tank flange, which is 5.0 in. (12.7 cm) thick and 103.5 in. (2.63 m) in diameter, is suspended from the top and held in place by a carbon steel bolting ring and twenty-six 2-in.-diameter (5.08-cm) alloy steel studs and nuts. The overall length of the tank is 425.98 in. (10.82 m). The body of the pump tank has an outside diameter of 80 in. (2.03 m) and is made of 2-in.-thick (5.08-cm) plate that is rolled and welded.

2. Tank Bolting Ring

The carbon steel bolting ring is used to clamp the pump tank to the pump support. The bolting is accomplished by use of twenty-six 2.000 x 4.5 in. (5.08 x 11.45 cm) alloy steel studs and nuts.

3. Pump Shaft

The Type 304 stainless steel shaft is used to transmit the torque generated by the pump motor to the impeller. It is 353.5 in. (8.98 m) in length and 28 in. (71.1 cm) in diameter at its largest point.

4. Shield Plug/Support Cylinder Assembly

The Type 304 stainless steel shield plug/support cylinder (SP/SC) is of cylindrical construction and has an overall length of 278.88 in. (7.08 m). The component has two functions: (1) to support the hydrostatic bearing housing and the stationary hydraulics and (2) to act as a radiation shield and thermal baffle. These functions are incorporated into the two major parts of the SP/SC assembly, namely, the shield plug and the support cylinder assembly.

The pump shaft rotates inside the inner cylinder. At normal running speeds, the shaft will pump all the sodium out of the annulus between the shaft and inner cylinder and this annulus will be filled with cover gas, thereby reducing friction and windage losses.

5. Static Hydraulics

The Type 304 stainless steel static hydraulics consist of the stationary parts of the pump hydraulics. This assembly can be subdivided into four parts: (1) the pressure casing, (2) the suction-side components, (3) the discharge-side components, and (4) the hydraulics restraining hardware.

6. Impeller-Inducer Assembly

A complete design description of the impeller-inducer assembly and related components is presented in Reference 3. A general description of the impeller-inducer follows.

The rotating pumping element consists of two components, the inducer and impeller. Their arrangement is as shown in Figure 2. Flow enters the inducer, and from the inducer feeds directly into the impeller. These components, along with the transition diffuser assembly, were adapted to the existing FFTF pump configuration and replace the FFTF pump impeller.

Impeller — The impeller is a shrouded radial-discharge centrifugal type. It has five full blades and five additional, partial blades at the discharge. The number of blades was chosen to optimize efficiency and generate the required head at the design point. Transition from four inducer blades to five inlet impeller blades is not uncommon in optimum design practice and creates no detrimental effects.

To assure long life, the inlet section of the blades is designed to preclude cavitation. This is made possible by including an upstream inducer that provides sufficient head-rise to eliminate impeller cavitation, either on the blade or in the vortices generated in the wear ring return flow.

The discharge diameter, number of blades, and blade angle were balanced so as to allow room for another diffuser and still generate the required head. This

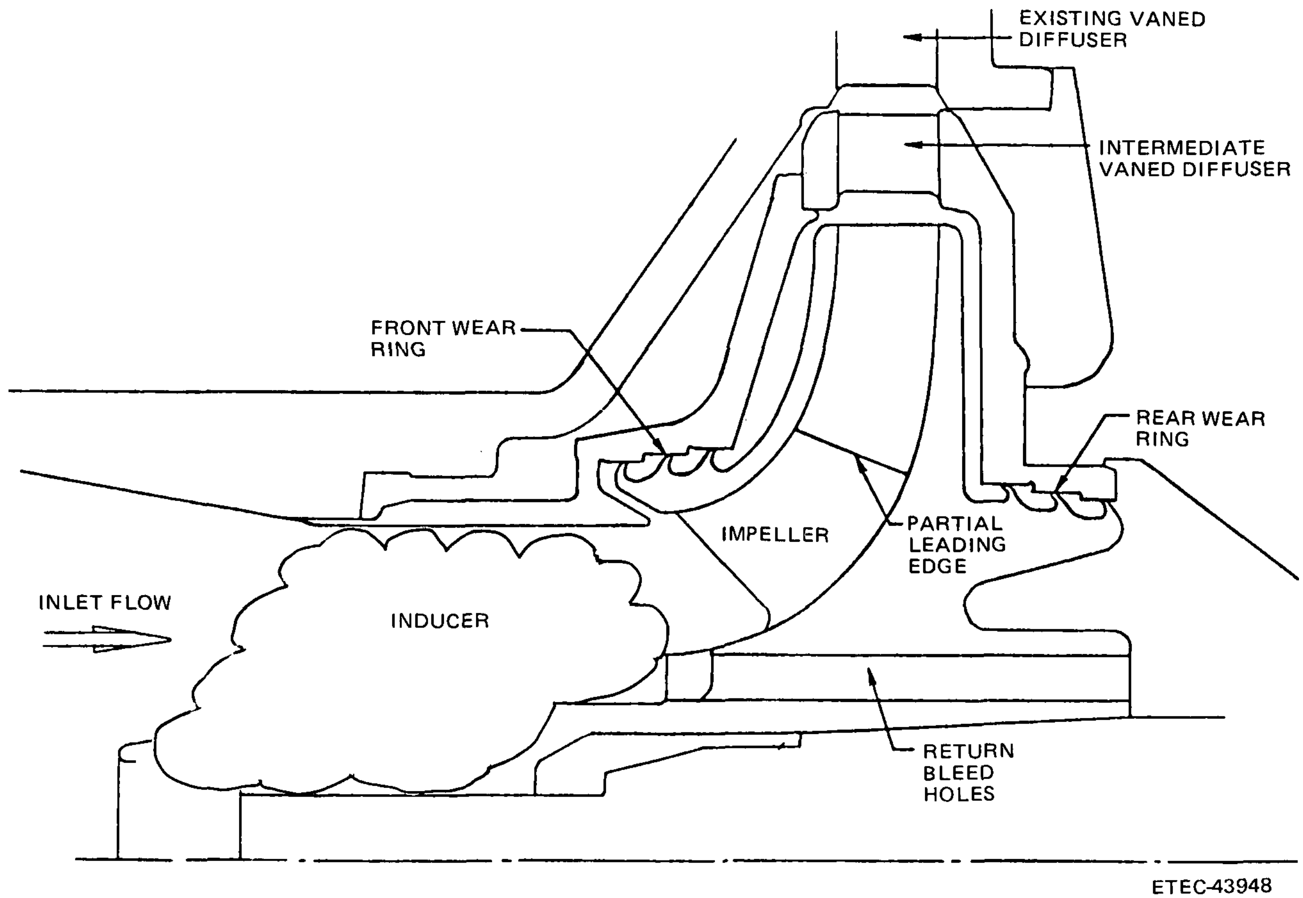

Figure 2. Impeller-Inducer Configuration

was based on previous Rocketdyne pump experience developed in the design and test of numerous centrifugal impellers used in the turbopumps of engines for the national space program.

The shroud and hub contour shapes and the blade camber distributions were selected to achieve a uniform loading and head generation distribution.

The required tip clearance is set by the rotor dynamics of the pump in the facility. This is somewhat larger than clearances commonly used in waterjet practice. However, the effect of the larger clearance was included in both the performance and life analyses. To further avoid any potential for rubbing at the tip, the blade was designed for zero cant angle so that any blade movement would not decrease the operating clearance.

The hub contour was selected to optimize performance and match the required impeller inlet design. The inlet diameter was selected to achieve the desired suction performance and to maintain the flow coefficient in the region where confidence in long life is high. The discharge hub diameter was selected for optimum efficiency of the inducer-impeller combination. The contour shape of the hub, from inlet to discharge, was based on established procedures. The contour was optimized to achieve the proper head-rise distribution along the stream surfaces through the inducer.

The blade design includes such factors as leading-edge blade angles, blade camber distribution, blade thickness distribution, and leading-edge and trailing-edge sweep and blade solidities. These values were selected on the basis of previous commercial experience. In each case, the ISIP-II values are consistent with waterjet design experience at Rocketdyne. The blade design is of primary importance in achieving:

1) The optimum suction performance capability
2) Long life with no detrimental blade damage
3) The required head and maximum efficiency.

Intermediate Vaned Diffuser — A short ring diffuser was added between the impeller and the existing diffuser to increase the stable flow range of operation. This diffuser provided flow into the Westinghouse diffuser with a smaller angular variation over the flow range than would be available directly from the impeller.

The discharge width and number of vanes were set to match the inlet flow angles to the vanes of the Westinghouse diffuser. The eleven vanes of the intermediate diffuser were staggered between the eleven vanes of the existing diffuser to minimize boundary layer buildup and separation with the attendant loss in efficiency. The discharge diameter was set by the housing geometry and the inlet diameter was set by the impeller diameter, allowing sufficient clearance to avoid cavitation or fatigue damage to the impeller or diffuser.

The vane profile is a double-circular-arc design. The profile and thickness selected were consistent with hydrodynamic practice. The vane profile was selected to control hydrodynamic loading on the vanes to meet the required structural integrity.

The inlet vane angle was set to match the flow from the impeller at the design flow. The discharge angle was set to provide flow matching the inlet vane angle of the Westinghouse diffuser. The required vane angles and diameters combine to give a solidity that provides the required diffusion.

The diffuser was designed using the methods developed for the space program's centrifugal pump designs. These design techniques have been proven by tests over an extensive flow range.

7. Seals

The shaft seals are mechanical, oil-lubricated, rubbing-face seals. Their primary function is to prevent out-leakage of sodium vapor and cover gas to the atmosphere or in-leakage of the atmosphere to the pump tank. The seals and bearings are fully accessible and serviceable with the main portion of the pump fully assembled. The upper seal was a modified FFTF-type seal.

8. Oil Bearings (Radial and Thrust)

The upper radial bearing is a commercial, oil-lubricated, flanged, preloaded, tilting-pad journal bearing. The bearing assemblies consist of five centrifugally babbitted steel-backed pads held in place by hardened steel locating dowels and bolted-on end plates.

9. Bearing Support and Hydrostatic Bearing

The lower radial bearing operates continuously in sodium. This bearing is a sodium-lubricated bearing of the four-pocket hydrostatic type.

A description of the thrust bearing is presented in Reference 14. The pump shaft end clearance of 0.015 in. (0.038 cm) is controlled by the thrust bearing.

10. Disconnect Bellows

A stainless steel bellows assembly is used as a flexible connection between the static hydraulics assembly and the discharge-nozzle portion of the pump tank. This assembly prevents leakage of the high-pressure (impeller discharge pressure) sodium into the pump tank. The bellows assembly consists of three stainless steel bellows convolutions welded to a stainless upper bellows flange and a stainless steel lower bellows flange.

11. Motor Support Stand

A carbon steel motor support stand, of cylindrical construction, is used to mount the drive motor to the pump. The lower flange of the motor stand is mounted on top of the shield plug/support cylinder and is bolted to the pump tank with 30 alloy steel studs and nuts. The motor is connected to the motor flange (upper flange) by use of 18 bolts.

12. Coupling

The connection between the pump shaft and the drive motor rotor is made by a commercial double-flexing disk coupling. The coupling consists of a pump hub attached to the pump shaft by a tapered fit and key, a motor hub keyed to the motor rotor, and a spool piece between the two hubs.

13. Drive Motor

The drive motor is a vertical-shaft induction motor with dripproof enclosure. It has a wound rotor with Thermalastic Class B insulation. It is of the two-bearing design utilizing a combined thrust and guide bearing located above the windings and a separate guide bearing located below the windings. All bearings are oil lubricated.

Ventilation — The centrifugal action of the rotor draws air in through vent openings and directs this air over the oil pots to cool the bearings. The air is then exhausted through mufflers to reduce noise.

Torsional Damper — A Houdaille viscous torsional damper (Part No. 708134) is mounted on a shaft shoulder between the rotor core and the lower guide bearing.

Anti-Reverse Rotation Mechanism — The drive motor is equipped with a ratchet and pawl assembly to prevent reverse rotation. At standstill and at low speed (below pony motor speed), the pawl contacts the ratchet teeth. At higher speeds, centrifugal force disengages the pawl from the ratchet teeth. This mechanism is located above the rotor windings on the motor shaft.

14. Pony Motor

The Westinghouse pony motor consists of a gearbox and an ac induction motor. The drive motor is a 25-hp, 480-V, three-phase, 60-Hz, 1750-rpm motor with a dripproof enclosure. Two 120-ohm nickel resistance temperature detectors are located in the motor stator. The gear unit is AGMA Class 1 with an 18.6-to-1 gear ratio.

The pony motor is capable of starting the drive motor and pump from a standstill and accelerating it to a speed of 94 rpm.

15. Instrumentation and Accessories

Temperature Detectors — Resistance temperature detectors are mounted in the motor stator, bearings, and gear motor. These resistance temperature detectors are nickel wire.

Proximity Probes — The pump shaft has a proximity probe magnetic target located above and attached to the bearing journal. This device is used to measure the true position of the shaft in relation to the hydrostatic bearing.

Accelerometers — An accelerometer is mounted on the upper portion of the motor support stand. This instrument is not part of the motor assembly but is installed to monitor motor operation.

Tachometer Generator — The GE Type BC-46 tachometer generator is a dc generator mounted inside the pony motor support. It is driven by two matched timing belts. The tachometer generator output is fed to a speed indicator located in the SPTF control room.

Oil Lift System — The oil life pump is driven by a 3-hp, 1200-rpm ac induction motor in a dripproof enclosure. The pump is a positive displacement Gerotor pump, Model H-3-B10B1. The oil lift system provides oil flow to each thrust shoe.

Surge Capacitors — Westinghouse Type 633A918A01 radiation-resistant surge capacitors are mounted in the main lead conduit box to provide voltage surge protection.

Space Heaters — Space heaters are installed in the main motor housing to prevent moisture condensation on the motor coil surfaces when the motor is not in operation.

Noise Mufflers — Noise mufflers are located on air intake and exhaust vents.

Overrunning Clutch — A specially designed Formsprag overrunning clutch couples the pony motor to the drive motor, which allows the drive motor to overrun the pony motor. The coupling can accommodate 1/4 degree of angular misalignment and 0.020 in. (0.05 cm) of parallel misalignment simultaneously.

16. Oil Circulation System

The oil circulation system has two main functions:

1) To provide a pressurized barrier between the pump cover gas and the containment atmosphere
2) To provide a medium to carry away friction-generated heat from the seals and bearings.

A more detailed description of the lube oil system is presented under Facility Description.

VI. DESCRIPTION OF TEST FACILITY

A. TEST FACILITY

The primary function of the SPTF is to test liquid sodium pumps. The pump is installed in a pump tank that is part of a piping loop housed within a test building. The pump is controlled remotely from a control building. The flowing sodium loop is serviced by another loop used to control the sodium temperature. SPTF is also provided with tanks and piping for adding and removing sodium. Various other systems support the operation of the sodium loop by providing purification and sampling capability, cover gas control, and temperature control. Assembly, disassembly, and cleaning of the test pump are done in the Component Handling and Cleaning Facility (CHCF) located west of the SPTF. The stiffleg derrick at the CHCF is used for handling the test pump and other components. Figure 3 shows the CHCF and stiffleg derrick in relation to the SPTF.

Several photographs depicting the test article and facility are presented in the text to enhance understanding or show details of special interest. A list of official ETEC photographs taken during the ISIP-II test program but not presented herein is presented in Appendix A.

The relationship of the major components and systems at the SPTF is shown schematically in Figure 4 and is explained in the following paragraphs.

1. Main Flow Loop System

The main flow loop (MFL) system includes the main flow loop, the test pump, the feed line and tank, the drain line and tank, the sodium cooler, and piping. The main flow loop consists of 16-, 18-, and 28-in. (40.6-, 45.7-, and 71.1-cm) piping with five butterfly-type control valves, a mixing tee, a drain tee, a cooler tee, a venturi flowmeter, and a pressure reducing device. The permanent portion of the loop is 18-in.-diameter (45.7-cm) Type 304-H stainless steel pipe, arranged in a U-shape. The suction piping and discharge piping for the pump have a configuration designed to hydraulically simulate the FFTF piping.

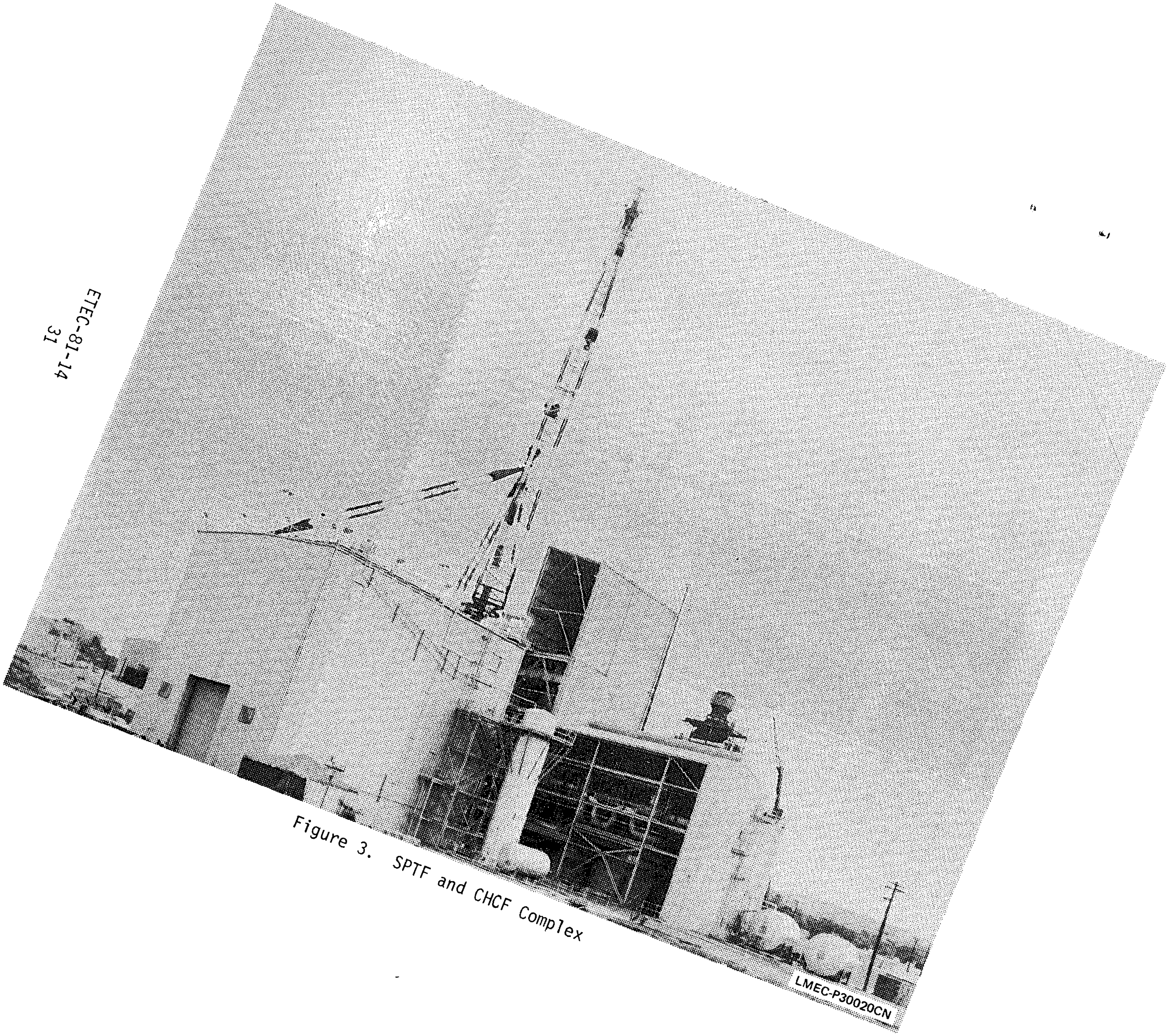

Figure 3. SPTF and CHCF Complex

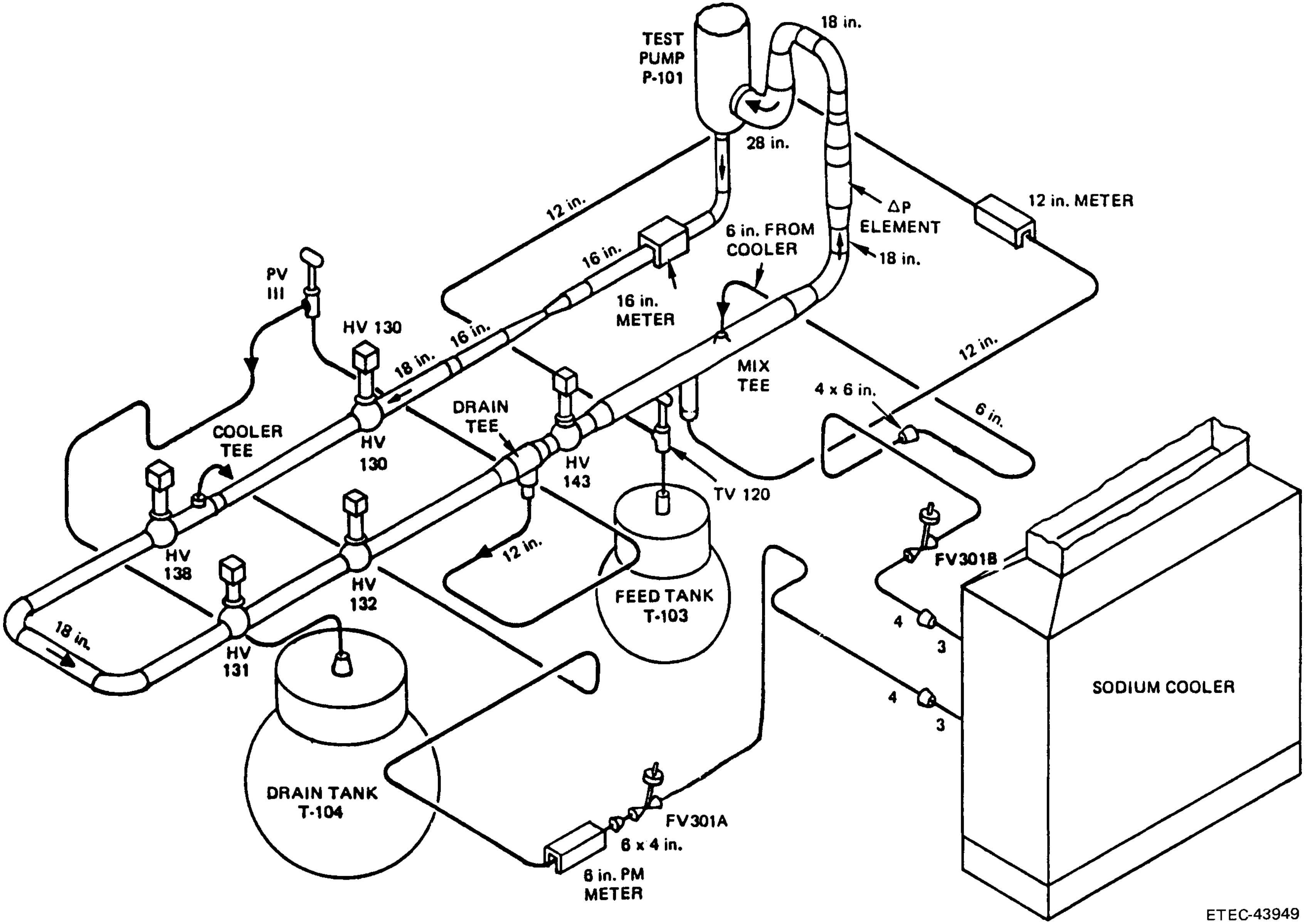

Figure 4. SPTF Pump Flow Loop — Isometric Sketch

The pump tank serves as the anchor point for the main flow loop. Feed and drain tanks are connected to the MFL by 12-in. (30.5-cm) piping.

Excess heat generated in the main flow loop sodium by the test pump is rejected to the atmosphere by the sodium cooler.

The piping is supported by spring hangers and tied to the building structure by vibration snubbers so that the combination of hangers and snubbers allows controlled movement during thermal expansion and contraction, as well as seismic activity.

2. Inert Gas and Vent System

Argon is used (1) to maintain an inert atmosphere over the sodium and inside sodium containment, (2) to provide gas pressure for sodium transfer and pressure testing and for controlling static pressures at desired values during normal operation, and (3) to deliver an inert sweep gas to the test pump. Two main headers deliver argon to the using systems. A low-pressure header carries argon gas at 100 psig (786 kPa) from a liquid-argon storage tank. This 100-psig argon is reduced in pressure to meet most of the normal operating requirements. The high-pressure header carries argon gas at 500 psig (3544 kPa) from a bank of bottles. Ten K-bottles provide an emergency supply of inert gas to the pump tank. These cylinders are located at the pump deck. The emergency supply is provided to ensure safe draining of the MFL system.

A major portion of the cover gas is released through the vent system. This system collects discharge gases from the test pump tank, the feed tank, and the drain tank. Vent gases are discharged to a knockout drum that condenses and holds entrained sodium out of the vent gas. Vent gas then flows through a vent stack and is discharged to the atmosphere above the highest SPTF building's roofline. A positive vent seal is installed on the outlet of the stack to prevent air backflow down the stack.

Pressure safety valves for the test pump tank, the feed tank, and the drain tank discharge directly into the vent stack, bypassing the knockout drum.

3. Electrical System

Two circuits supply electrical power to SPTF from the Burro Flats substation. Each circuit is 4160 V, three-phase. One circuit supplies 4160-V power for the test pump drive motor through a 5-kV air circuit breaker in the electrical equipment room. The other circuit supplies power to 4160-480/277-V facility transformers. Facility power is controlled through a motor control center (MCC) and a heater control center (HCC) in the electrical equipment room.

The MCC has circuit breakers to divide the power to equipment and to circuit breaker panels for further power control. The HCC directs and controls power to the heaters on sodium systems and supporting systems. An uninterrupted power supply (UPS) is connected into some selected circuits to provide temporary power in case of a power outage. The UPS consists of batteries, a battery charger, an inverter, a transfer switch, and a bypass switch.

Lighting is provided by a combination of mercury-vapor fixtures and fluorescent and incandescent bulbs. Some exterior lighting is controlled by a photoelectric cell. Battery-powered emergency lights are located throughout the facility.

Receptacles for 120-V and 240-V power are located throughout the facility.

Communications within the facility are provided by intercom, public address system, and portable radios.

A low-resistance grounding system is provided to ground equipment and instrumentation.

4. Site and Buildings

The SPTF test site is composed of a control building, a test building, a rheostat enclosure, and utilities. The control building includes the electrical equipment room, the control room, and an office area. Below the control room is a subfloor to carry wiring; above is an attic space, which has an electrical conduit area.

A new control room housing the process control panel, operator control console pit, and instrument recorder racks is shown in Figure 5. The digital data acquisition system (DDAS) computer room housing the computer system is shown in Figure 6.

The test building high bay extends 114 ft (34.7 m) above the ground. Platforms at intermediate levels provide access to corresponding platforms in the low bay. The low bay houses most of the sodium systems and provides a concrete-lined pit for the feed and drain tanks.

A rheostat enclosure houses the liquid rheostat and its associated components.

5. Sodium Sampling and Purification System

The sodium sampling and purification systems include two electromagnetic pumps, a plugging meter, a multipurpose sampler, a cold trap with external heat economizer, and interconnecting piping and valves. Sodium to be purified and/or sampled may be taken from the MFL, feed tank, or drain tank and returned to the MFL, feed tank, drain tank, or sodium cooler. The piping in the sodium sampling and purification systems is also used for transferring sodium during loading, offloading, and filling and for transfer between feed and drain tanks.

6. Sodium Loading System

There are sodium piping connections for a sodium loading system along with electrical and inert gas service outside of the test building. Sodium is loaded by gravity, and unloading sodium in the SPTF is accomplished by the purification

Figure 5. SPTF Control Room

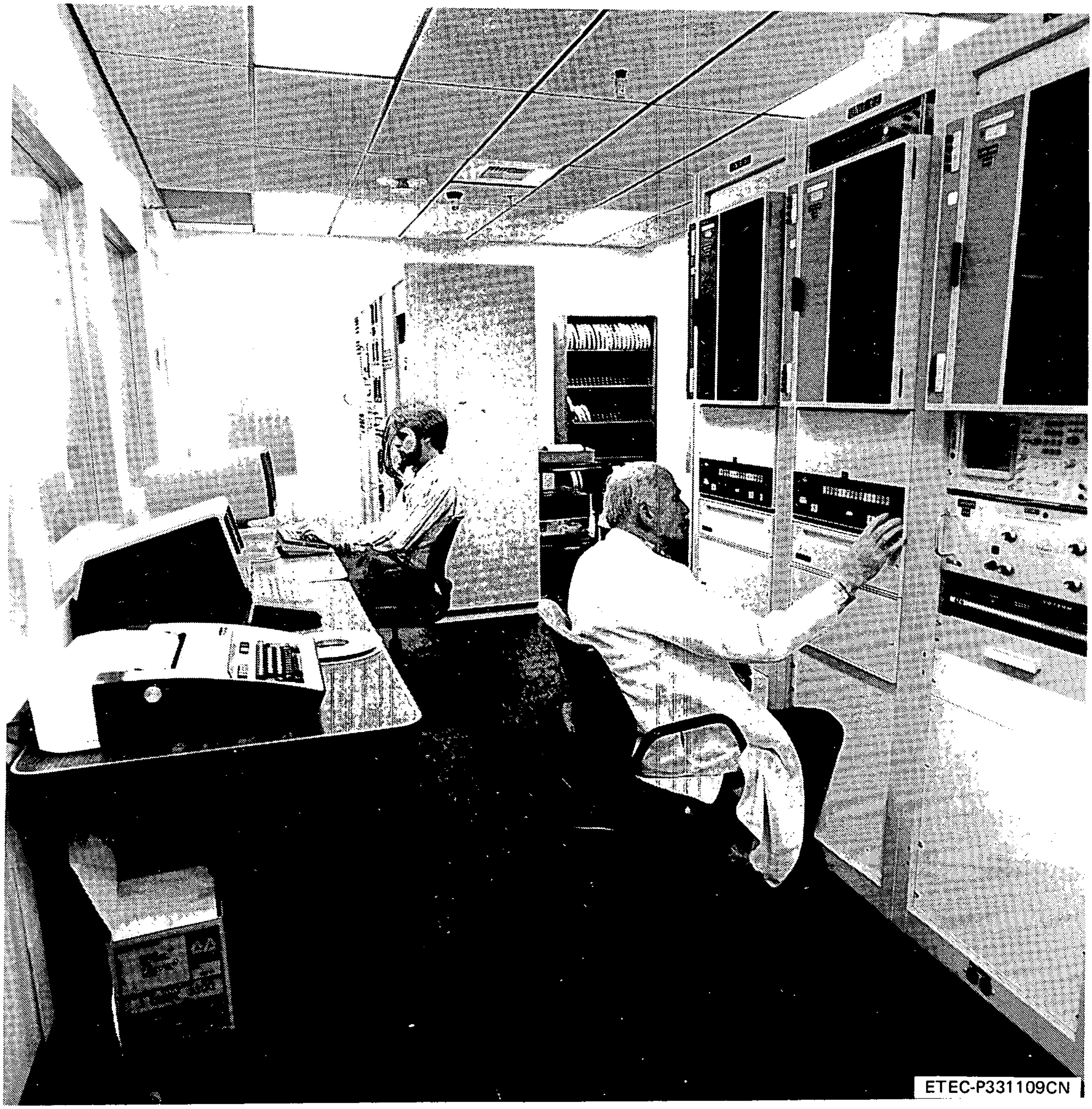

Figure 6. SPTF DDAS Computer Room

system pumps. Sodium is loaded into the sodium system through the purification system. To unload sodium, the purification pumps can take suction from the drain tank, the feed tank, or the MFL and discharge the sodium into drums.

7. Electrical Heating System

Electric resistance trace heaters are used to control the temperature of the sodium, inert gas, and vent systems. The heater power is controlled by variable transformers, on-off temperature indicator controllers that actuate relays, proportional automatic-reset temperature indicator controllers that trigger silicon-controlled rectifiers, and hand switches.

The heating system is separated into zones having uniform mass and cross sections. Each zone is controlled by a temperature controller. The various sodium systems have different control requirements. The MFL, the cooler loop, the feed tank, the drain tank, and the drain line are capable of programmed temperature control. The purification system and the vent system are under manual temperature control.

Thermal insulation on piping and components is included within the electrical heating system.

8. Compressed Air System

Air pressure is used for positioning and actuating some valves. There are compressed air outlets available throughout the test building for maintenance.

The system has two compressors, which normally operate in a lead-lag mode to supply compressed air at 125 psig. The air moves from the compressors to an air receiver tank and then through a filter and a dryer before entering the instrument air header or the utility air header. Utility air use is automatically restricted by control valves if the system pressure drops below 90 psig.

9. Fire Protection System

The fire protection system serves to detect sodium leaks, detect fires in the buildings, contain leaking sodium, and provide automatic fire suppression. Fire extinguishing equipment is available for use by personnel.

There is an alarm system for fires and a separate alarm system for sodium leaks. The leak detectors are installed at strategic locations where the probability of a sodium leak may be greater than at other locations. Fire detectors in SPTF work in two ways: One type is a heat detector sensitive to a fixed temperature as well as to a rate of temperature rise; the other is a smoke detector sensitive to combustion products (even if smoke is not visible).

Alarm lights actuated by leak detectors and fire detectors are located in the control room. Fire horns in the control room and test building are activated by any fire signal. The air conditioning and ventilation system for the control building and rheostat enclosure is automatically turned off by a fire signal from the control building or rheostat enclosure.

A Halon system is installed in the control room, in the subfloor plenum beneath the control room, and also in the electrical equipment room. Halon is released automatically upon a signal from a heat detector or by manual actuation. Water sprinklers and portable water extinguishers are provided in the control building at ground level to protect areas without Halon. The water sprinklers operate with standard fusible links. Various portable extinguishers are available for use throughout the entire facility. Sodium fires in the test building are extinguished by using NA-X from portable extinguishers, buckets, vessels with hose reels, or a trailer-mounted unit. For personnel protection, there are two safety showers and eyewash stations at ground level outside of the test building.

Protective clothing and self-contained breathing apparatus are also available at SPTF.

B. COMPONENT HANDLING AND CLEANING FACILITY

The CHCF provides the capabilities for assembling, disassembling, cleaning, and handling the pump internals. The facility consists of a building in which the pump can be assembled and disassembled while protected from the elements. Included is an outdoor cleaning tank in which the pump internals assembly can be immersed in an alcohol cleaning solution. Mounted on top of the building is a 70-ton (63.5-Mg) derrick capable of lifting the pump internals assembly (∿66 tons, or ∿60 Mg) out of the pump tank in SPTF and transporting that assembly to the cleaning tank and into the building through one of the roof hatches. The building has three 18-ft^2 (5.49-m^2) roof hatches. Inside the building, under one of the hatches, is a 40-ft-high (12.2-m) assembly/disassembly (A/D) station designed to hold components of the pump internals and provide personnel access during assembly and disassembly operations.

The building also has a bridge crane inside with 60- and 15-ton (54.4- and 13.6-Mg) hooks to permit handling of component parts without opening the roof hatch to the derrick.

C. TEST ARTICLE ASSEMBLY AND HANDLING

Handling and assembly of the test article were basically in accordance with the FFTF prototype and primary pump operations and maintenance manual (OMM). N2660MM000001 covers those changes in the manual necessary for assembling ISIP components.

One set of FFTF primary pump special tools required for pump assembly at ETEC was provided by HEDL. Special tools peculiar to the ISIP configuration were provided by ESG. ETEC provided the required general-purpose tools and special plant tools.

Assembly of Pump Internals — Assembly of the pump internals was performed in the aforementioned pump assembly stands at CHCF.

The impeller assembly was installed on the pump shaft with the shaft oriented upside down. In Figure 7, the shaft (wrapped in plastic sheeting) is shown in this orientation in the assembly stand. The lower bearing support assembly was also installed at this time.

A turnover fixture was then installed on the impeller end of the pump shaft. The shaft assembly was lifted from the assembly stand by the derrick and moved to an outside area for turnover. Figure 8 shows the shaft assembly ready for turnover.

A Gallion mobile crane was used for assistance in rotating the shaft to a horizontal position as shown in Figure 9. The entire shaft assembly was set onto a turnover support fixture as shown in Figure 10. The derrick hook was then reattached to the drive end of the shaft. The turnover fixture was removed from the shaft and the shaft was reinstalled into the CHCF assembly stand — impeller end down.

The shield plug/support cylinder (SP/SC) was set into the assembly stand over the pump shaft assembly as shown in Figure 11. The shaft assembly was then lifted up into the SP/SC and secured. The upper shaft bearing housing, bearing, and seals were installed at this time. The entire assembly was then removed from the assembly stand and placed on an auxiliary stand to allow the static-hydraulics assembly to be placed under the assembly stand. The SP/SC assembly was then installed onto the static-hydraulics assembly.

A plastic bag was positioned around the assembled pump internals. Figure 12 shows the inerting bag over the pump internals during transfer of the assembly to SPTF.

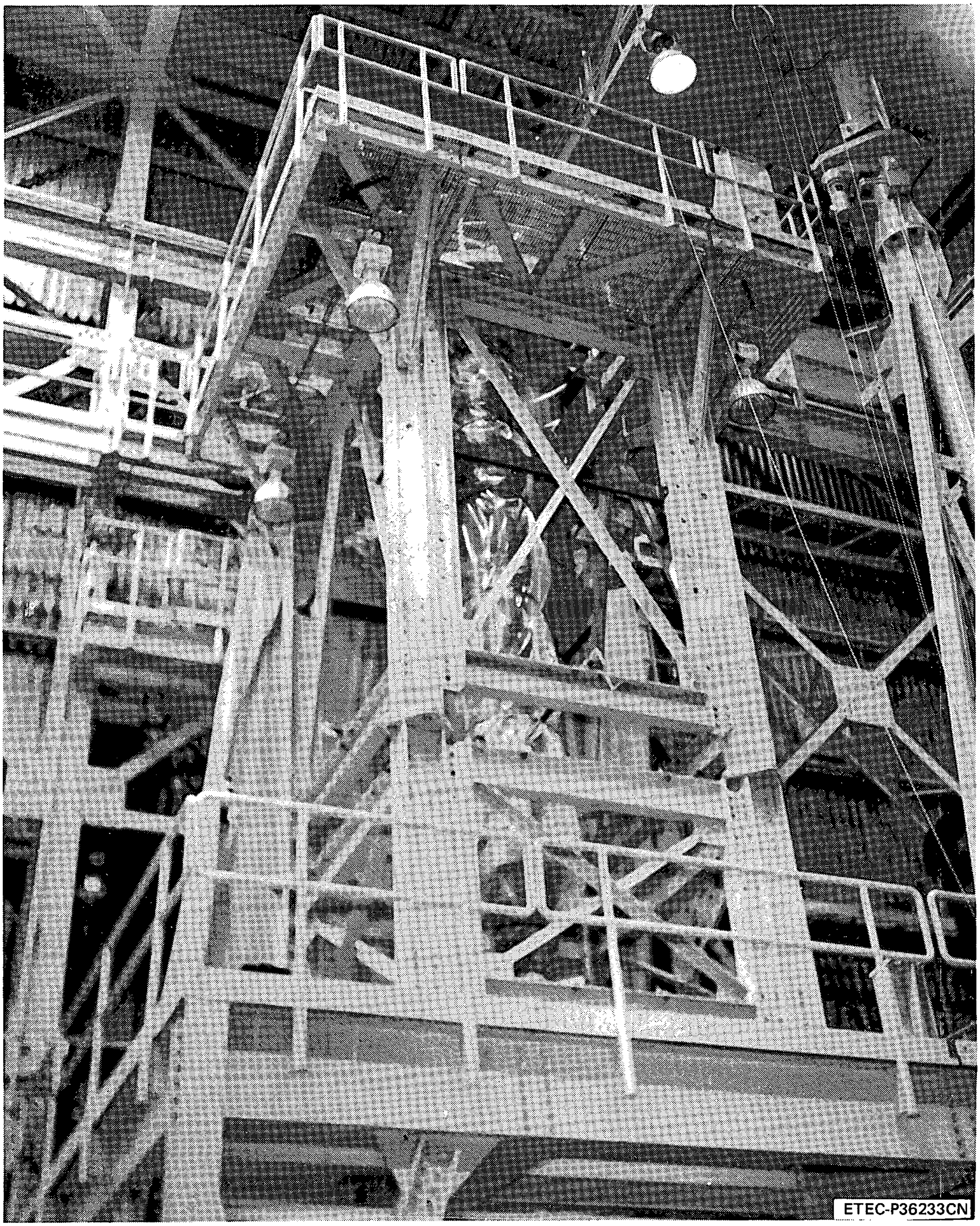

Figure 7. Pump Shaft in CHCF Assembly Stand

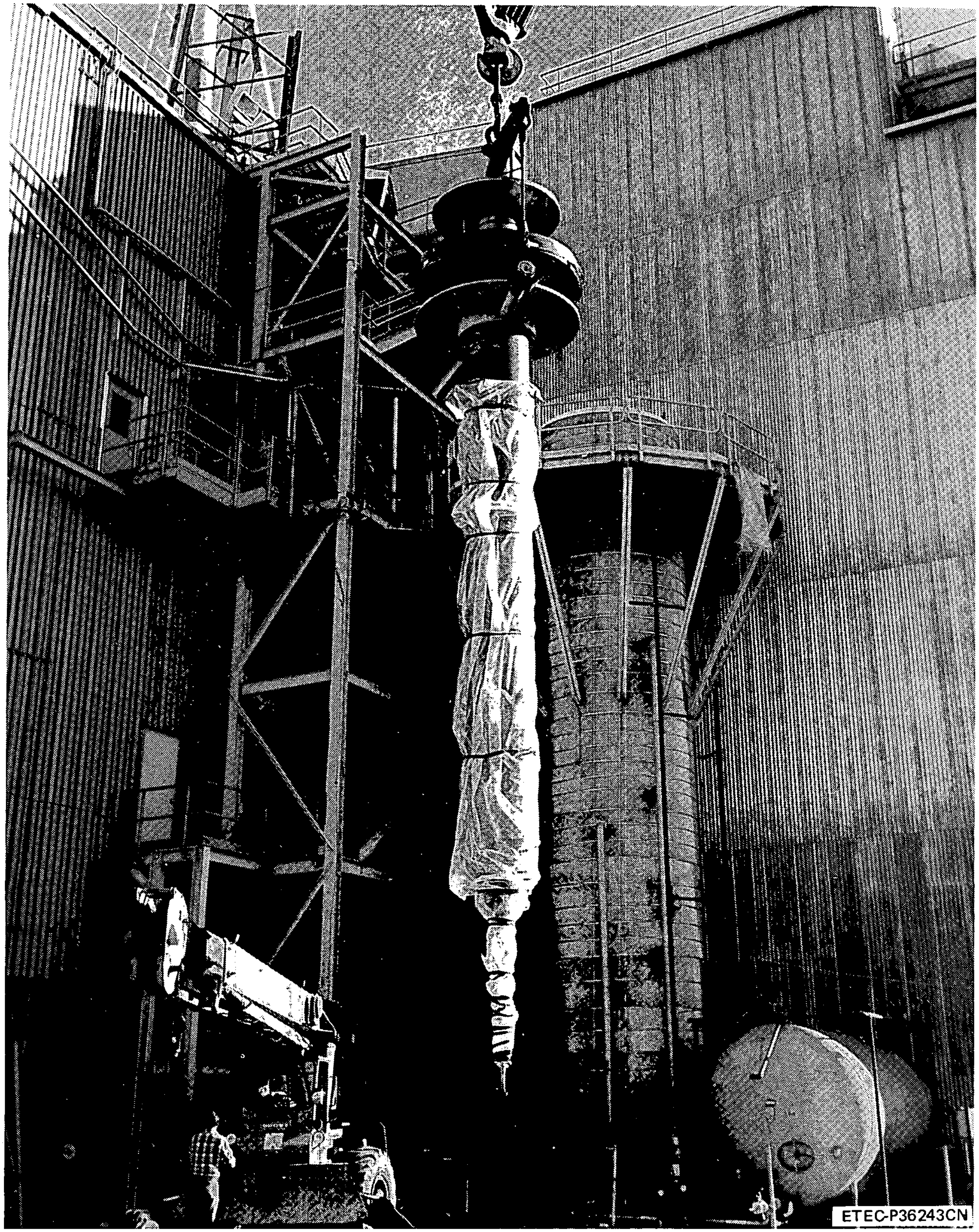

Figure 8. Pump Shaft Ready for Turnover

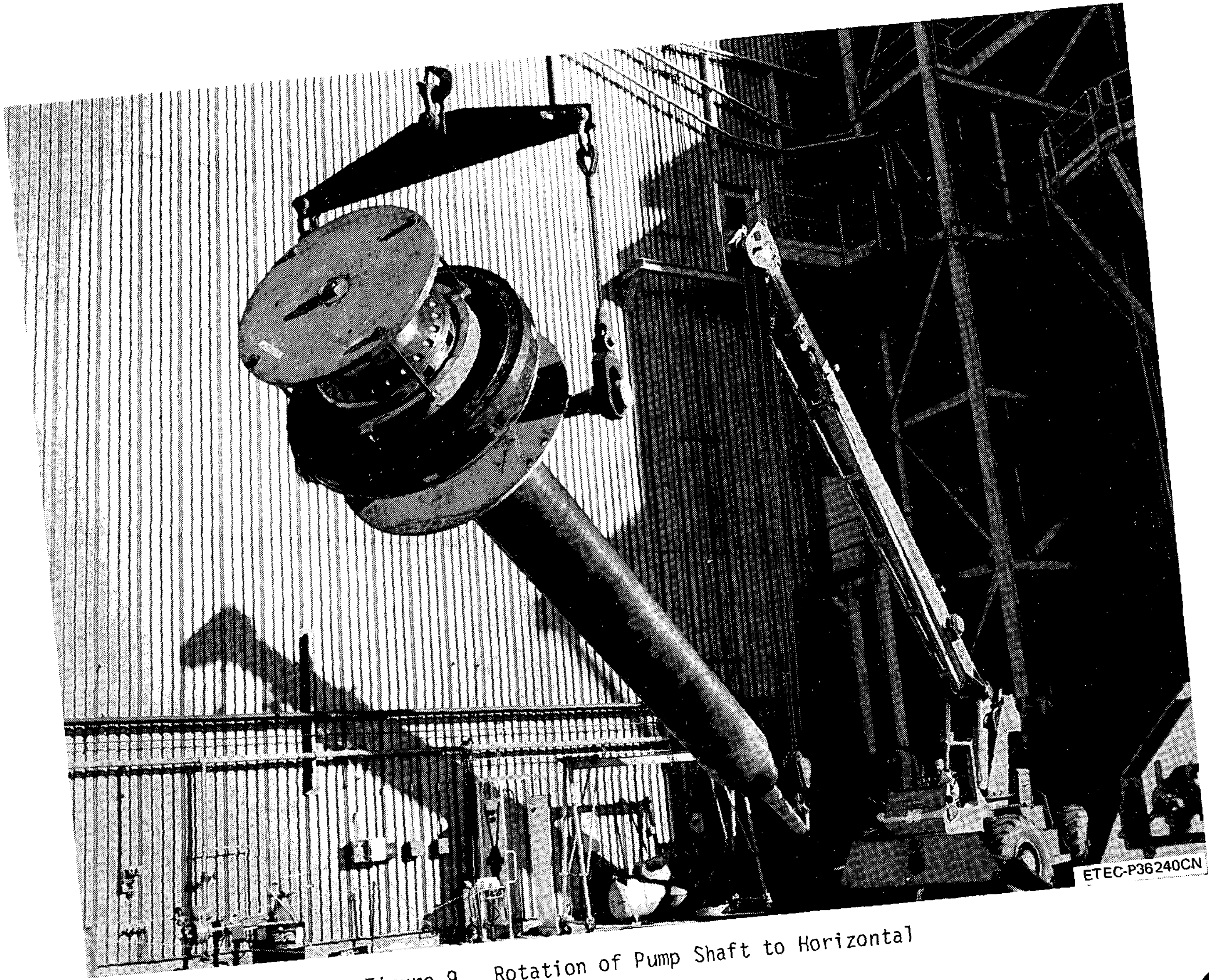

Figure 9. Rotation of Pump Shaft to Horizontal

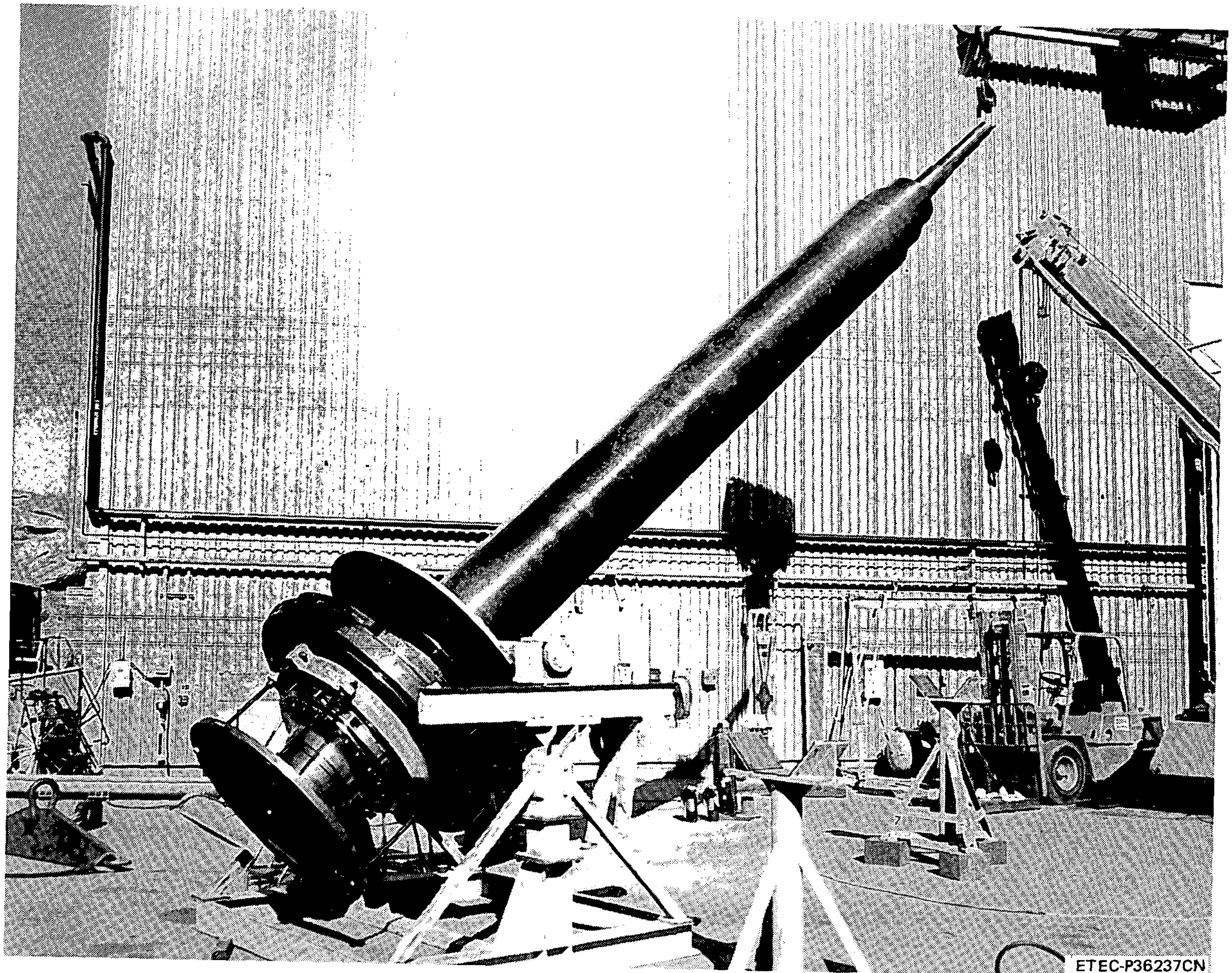

Figure 10. Pump Shaft Assembly in Turnover Fixture

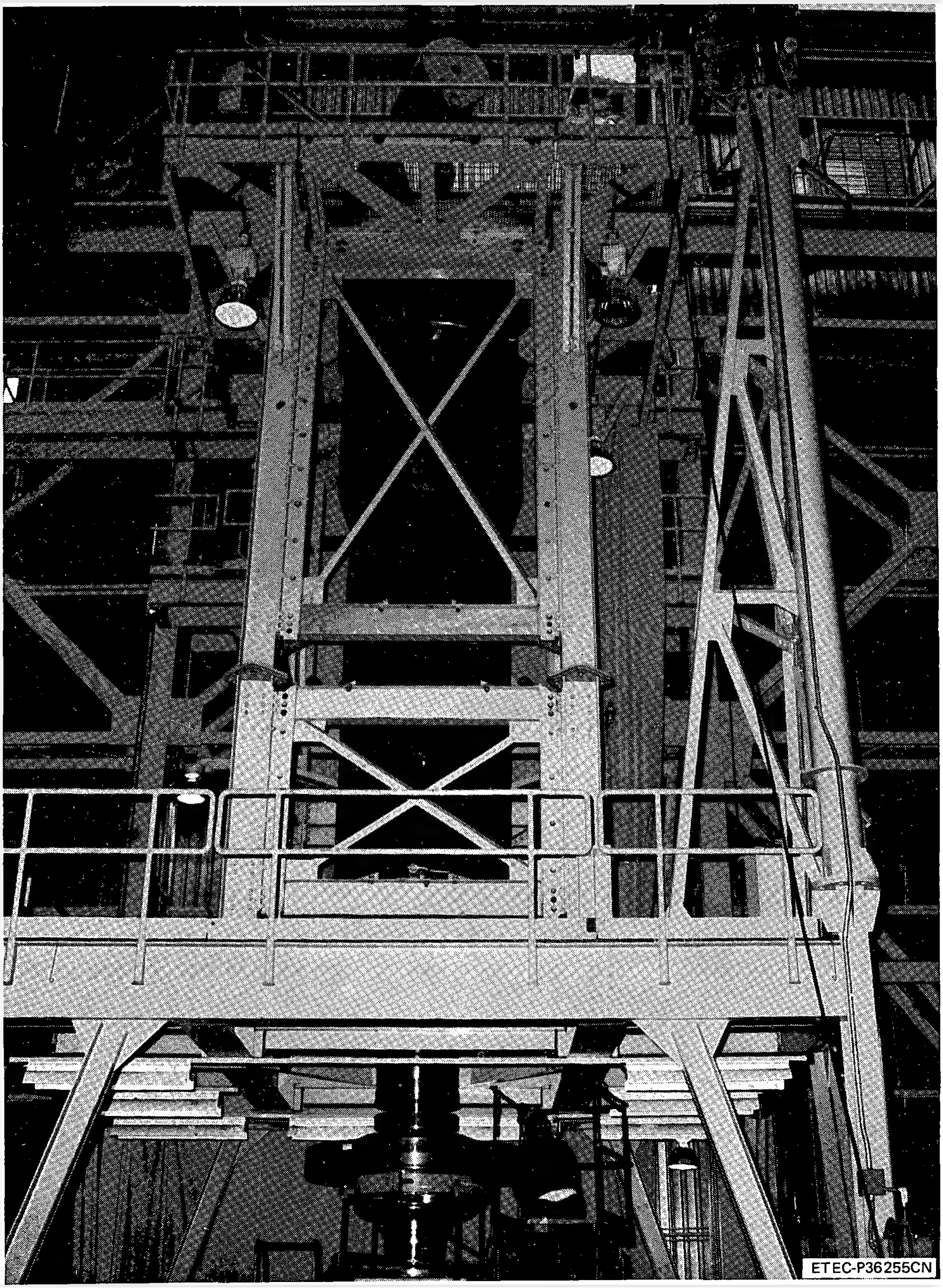

Figure 11. Shield Plug/Support Cylinder in Assembly Stand

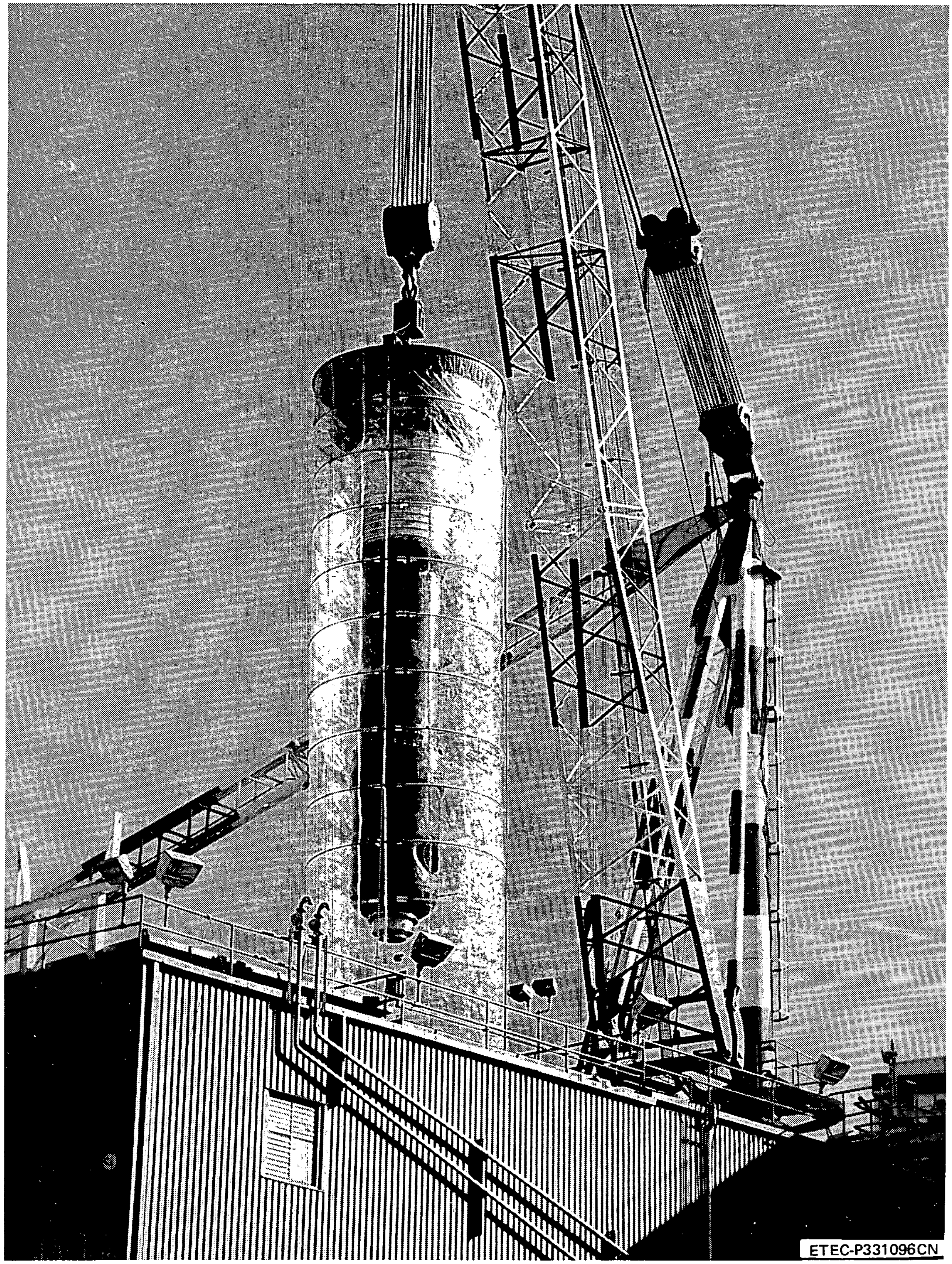

Figure 12. Assembled Pump Internals in Inerting Bag

The pump internals assembly bag was attached to an inerted bag that had previously been placed over the top of the pump tank. The internals bag was then inerted and the joint between the two bags was opened, allowing the pump internals to enter the pump tank in an inert atmosphere. The pump internals assembly is shown being installed into the pump tank in Figure 13. After the internals assembly was installed, the inerting bags were removed and pump assembly was completed.

The main motor stand and main motor were then installed, and the drive coupling was connected between the main motor and the pump shaft flanges.

D. LIQUID RHEOSTAT DESCRIPTION

The liquid rheostat and control are facility support equipment, not specifically ISIP test articles.

The liquid rheostats and control provide a complete operating system to control the speed of the liquid sodium pump driven by a wound-rotor induction motor. Three basic functions are provided: speed control, mode control, and protection. In general, the functions provided are as follows.

1. Speed Control

The speed of a wound-rotor motor can be controlled under various load conditions by varying the secondary (rotor) resistance. Resistance is provided by using two electrodes (per phase) immersed in an electrolyte. The value of resistance is varied by changing the distance between (or separation of) the two electrodes. Motor load must be greater than 10% to permit effective speed control.

While the rheostat provides a physical means of varying the secondary resistance, it is the regulator supplied as part of the control that determines what the separation of the electrodes should be to provide the proper resistance

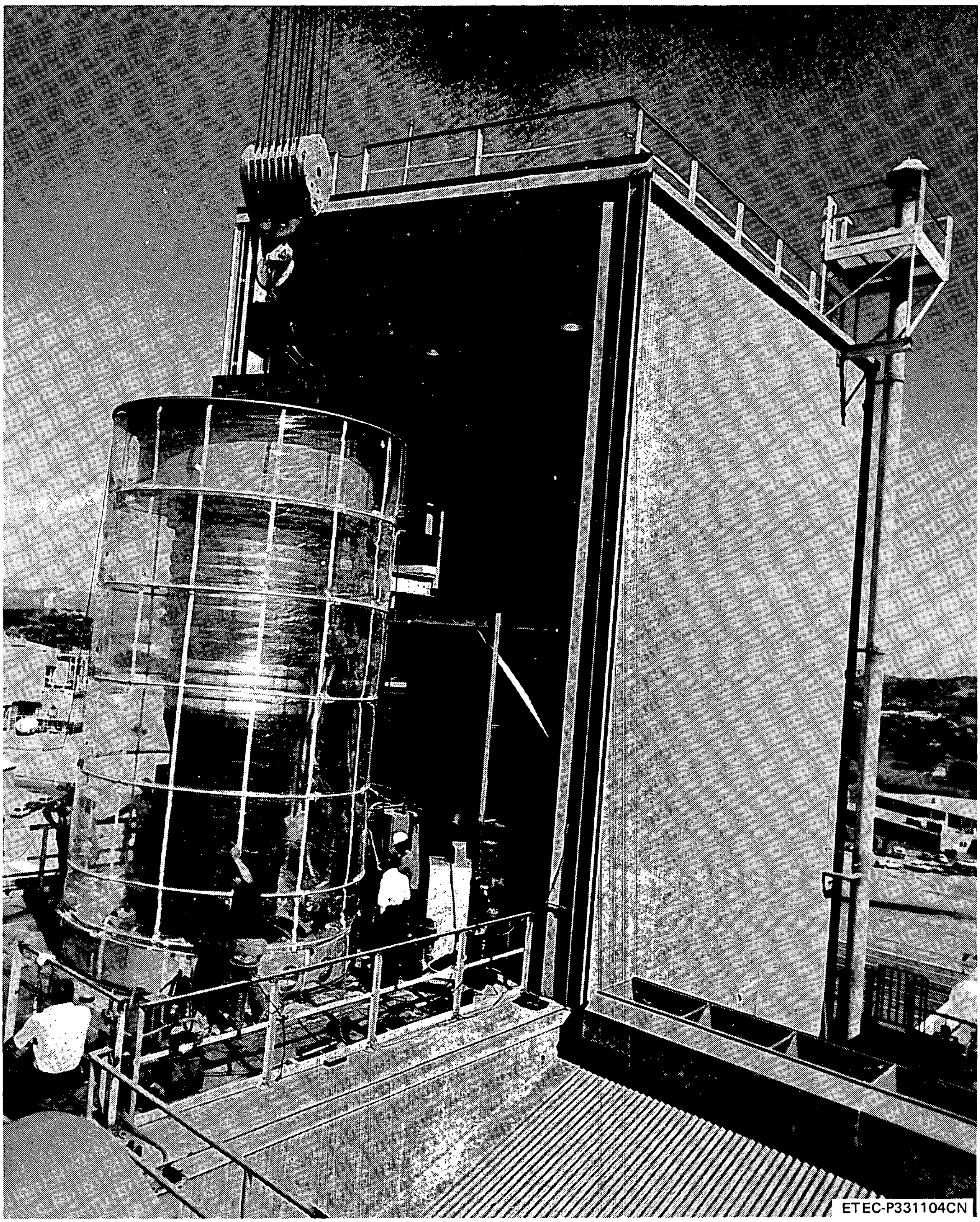

Figure 13. Installation of Pump Internals into Pump Tank

and, ultimately, the desired speed. Input and feedback signals are processed in the regulator, and an output signal is generated to control the rheostat drive motor, which, in turn, positions the electrodes properly.

2. Mode Control

The rheostat system can be operated in any one of the three following modes.

Manual Mode — Electrode separation is controlled directly by the operator by means of pushbuttons at the rheostat or control console.

Local-Automatic Mode — A speed reference is generated at the controller. The operator controls the speed of the pump by operating the increase and decrease pushbutton and a vernier potentiometer on the controller or by operating the increase/decrease hand switch on the control console. This is a speed-regulated mode with tachometer feedback.

Console Mode — This is another automatic mode of operation. A flow reference signal and a speed signal are provided to the controller. Electrode separation is controlled by the regulator in response to these signals. The operator controls pump speed in this mode by means of a Honeywell-supplied control on the control console.

3. Protection

Sensing, annunciation, and shutdown are provided to protect equipment from overtemperature, overloads, power loss, etc. Shutdown for the rheostat system is defined as deenergizing the rheostat drive motor to prevent further motion of the electrodes. Certain fault conditions also generate a shutdown signal for possible overall system shutdowns.

Visual annunciators are provided with the control. Certain fault annunciation signals are provided for a master annunciator.

E. ACCEPTANCE TEST PROCEDURES

After completion of FFTF testing in 1977, the Sodium Pump Test Facility underwent modifications to extend the facility's capability to test large sodium pumps. The modifications included addition of a high-flow sodium loop, an expanded sodium purification capacity, an expanded electrical power supply, additional instrumentation, a new digital data acquisition system, and a larger and more extensively equipped control room. The decision to perform the ISIP-II tests was made after these modifications were underway.

Most of the new or expanded systems in SPTF directly affected the ISIP-II test operation. The remaining systems had the potential for impact to the ISIP-II test program from the standpoint of operational safety.

ETEC prepared procedures to thoroughly check out, verify satisfactory operation, or ensure isolation of the various systems, as appropriate. Each of the various facility systems was checked out by performing an acceptance test procedure (ATP) before the system was put into operation for ISIP-II testing. The procedures were reviewed and approved by the ETEC Operations, Test Engineering, and Quality Assurance Departments.

An index and summaries of the ATPs used for the ISIP-II program are presented in Reference 4.

VII. INSTRUMENTATION

The SPTF instrumentation systems are described in this section. Methods of calibration and recommendations for improved data acquisition and data measurements for future test programs are discussed.

A. TEMPERATURE MEASUREMENTS

1. System Description

All pump performance temperature measurements except for the pump motor stator temperatures were made with Chromel-Alumel thermocouples. Externally mounted thermocouples were installed with Marimet installation blocks in accordance with PPM-I-A-5.1 except for the TE-199 pump discharge temperature units and TE-120 pump inlet temperature units. These were installed in thermowells. Pump internal thermocouples were installed by the manufacturer in accordance with pump assembly drawings. The majority of the Chromel-Alumel thermocouples were connected directly to a $150^{\circ}F$ heated reference junction. Low-level signals were fed directly into DDAS low-level multiplexer cards. A few parameters, such as pump inlet and discharge temperatures, were connected to millivolt-to-current converters and then to high-level DAS multiplexer channels. Temperature measurement system accuracy was $\pm 10^{\circ}F$.

2. Method of Calibration

Standard thermocouple tables were used to compute temperature from thermocouple output. The thermocouple measurement systems were calibrated by substituting a millivolt source for the thermocouple.

3. Recommendations

The measurement performance of the Chromel-Alumel thermocouples was found to be acceptable. This type of thermocouple is recommended for use in other programs where the operating environment is similar to that of the ISIP-II.

B. SPTF PRESSURE MEASUREMENTS

1. System Description

Sodium Pressure Transducers — The pressure measurement system consisted of pressure transducers, graphic display systems, signal conditioning, and the DDAS and its associated software. Figure 14 is a block diagram of a typical SPTF pressure measurement system.

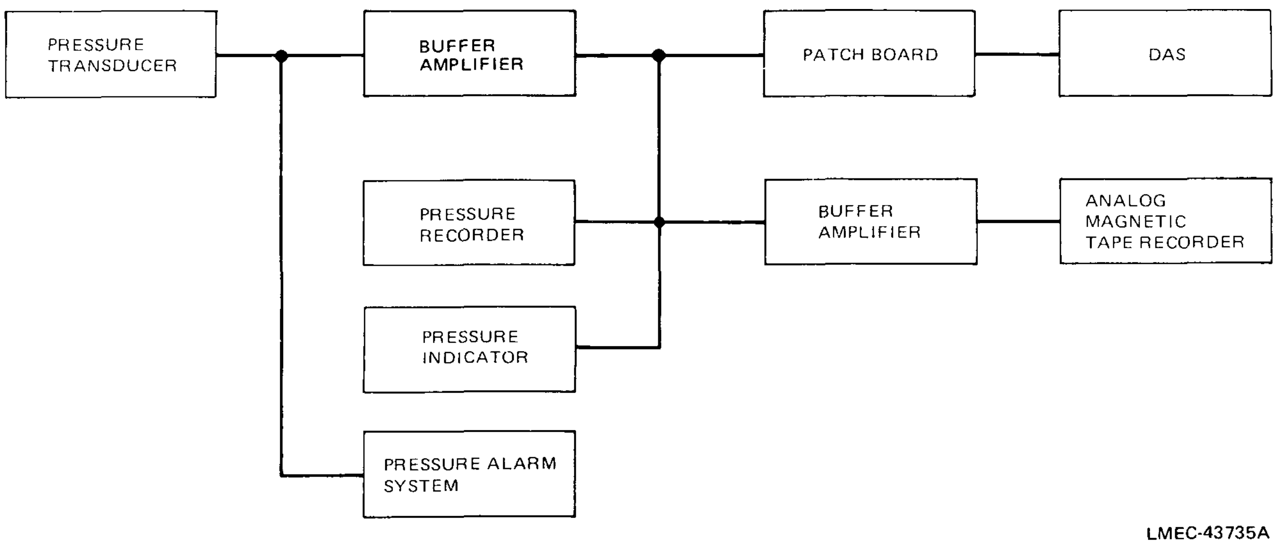

Figure 14. Typical Pressure Measurement Block Diagram

The sodium pressure transducers used at SPTF were built by Statham Instruments, Inc. (now Gould, Inc., Measurements Systems Division). Differential pressure, gage pressure, and absolute pressure transducers were used.

Figure 15 shows a cutaway view of a typical gage pressure transducer. Liquid NaK, a eutectic mixture of potassium and sodium, is used as the pressure transmission fluid. NaK has a freezing point of -9^{o}F (-22.8^{o}C) and a boiling point of 1445^{o}F (785^{o}C). Pressure in the sodium system is transmitted to the NaK through a bellows seal assembly. The pressure is transmitted through the NaK to cause deflection of a diaphragm in the transducer assembly. This deflection is sensed by a force summing system system consisting of a strain-gaged beam attached by a push-rod to the transducer diaphragm.

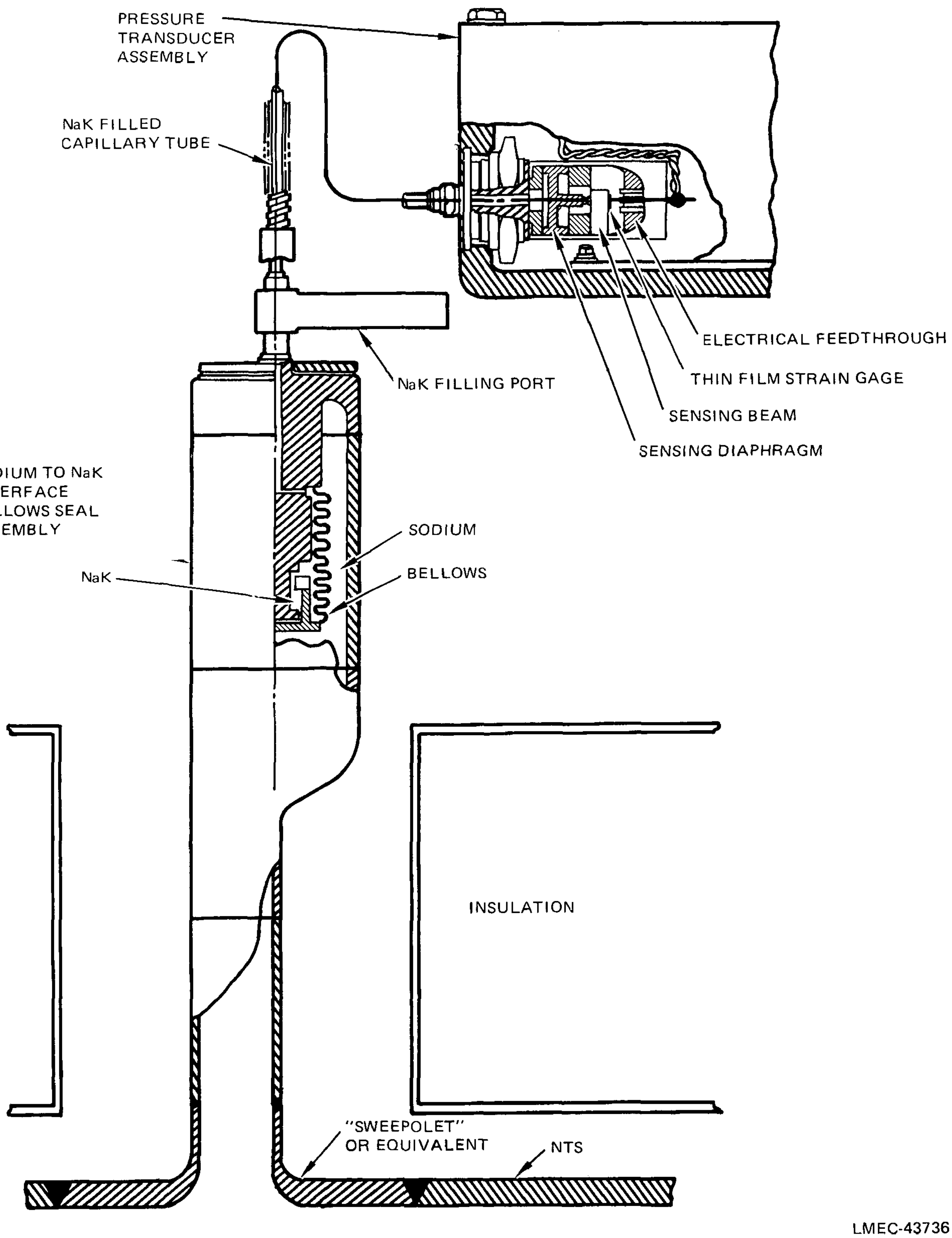

Figure 15. Pressure Sensor Installation on High-Temperature Sodium Piping

Vacuum deposited strain gages produce a change in electrical resistance proportional to pressure exerted on the diaphragm. The electronics system converts this change in resistance to a change in electrical current varying from 4 to 20 mA for the zero-to-full-scale pressure range.

A twisted, shielded pair of wires carries the signal to the control room. The current signal is converted to a voltage signal to be compatible with the DDAS multiplexer.

Pressure measurement system accuracy was ±2% of full range.

Pump Tank Cover Gas Pressure Transducer — The pump tank cover gas pressure was measured with a system different from that making sodium measurements. A sintered stainless steel filter was installed in the pressure line from the pump tank to the pressure transducer to prevent sodium vapor from contaminating or plugging the pressure transducer. The pressure transducer was a Statham aerospace-type transducer, Model PA-418-50. The transducer produced a 0-to-20-mV dc output signal for a 0-to-50-psia pressure range. It provided electrical simulation signals at both 20% and 80% of full range. The transducer could be removed for periodic calibration in the instrument laboratory.

2. Method of Calibration

Each pressure transducer was calibrated at room temperature in the ETEC Instruments and Standards (I&S) Laboratory prior to installation. Calibration data at 800°F, 1000°F, and 1200°F were obtained from the manufacturer.

A pressure equivalent to the step change in transducer electrical output when the electrical simulation (shunt calibration) is energized is determined from the laboratory calibration. This pressure value is called the key number and is used in determining scaling coefficients after the transducer is installed in the facility.

The basic scaling equation used to convert the electrical signal from the pressure transducer to engineering units of pressure is:

$$P = B(mV) + A \tag{VII-1}$$

where

P = the scaled output in pressure (psi)

B = the slope or sensitivity coefficient (psi/mV or in.-water/mV)

mV = the millivolt signal from the pressure transducer as recorded by the DDAS

A = the intercept coefficient (pressure units).

The B coefficient was calculated using the key number and the millivolt output of the transducer recorded during the system shunt calibration as follows:

$$B = \frac{KN}{mV_c - mV_o} \tag{VII-2}$$

where

B = the sensitivity coefficient

KN = the key number derived from the laboratory calibration

mV_c = the millivolt output of the transducer with the electrical simulation system energized

mV_o = the millivolt output of the transducer at system conditions.

During calibration of the measurement system, the pump was stopped to eliminate pressure perturbations within the system. For purposes of calculating sodium head pressure, it was assumed that the sodium loop was isothermal.

The differential pressure measurements on the flow venturi were corrected by computing a new A coefficient with the flow stopped such that the measured flow was zero. The equation used was

$$A = -B\ (mV_Z) \qquad \text{(VII-3)}$$

where

A = the intercept coefficient (in.-water)
B = the slope or sensitivity coefficient determined from the key number and electrical simulation signal
mV_Z = the output of the transducer (millivolts).

Pressure measurements for pump inlet, pump discharge, and other loop measurements were set up to read the pressure at the sensing port on the line. The calibration computer program calculated the true pressure at the sensing port based on cover gas pressure in the pump tank and sodium head pressure due to sodium level above the sensing port. The sodium head pressure was determined from the sodium level measurement (LT 40) and the sodium density, based on the bulk sodium temperature at the pump. In equation form, this calculated pressure was determined as follows:

$$P_c = P_g + \frac{\rho}{1728}\ (h + \text{LT } 40) \quad \text{(for transducers measuring in psia or psig)} \qquad \text{(VII-4)}$$

where

P_c = the calculated pressure in psia or psig
ρ = the sodium density (lb/ft^3) based on the measured sodium temperature
P_g = the cover gas pressure (psia or psig)
h = the elevation difference (in.) between the sensing port and the reference plane through the LT 42 lower nozzle
LT 40 = the sodium level (in.) as measured by LT 40.

The A coefficient for each measurement was then calculated using this calculated pressure:

$$A = P_c - B\,(mV_p) \qquad \text{(VII-5)}$$

where

A = the intercept coefficient
P_c = the calculated pressure determined from the preceding equation
B = the sensitivity coefficient
mV_p = the transducer output (mV) equivalent to the calculated pressure (as recorded on the DDAS).

The system was programmed to make the computations noted above, present the data to the operator with the difference information between the computer coefficients and those in residence, and allow the operator the option of updating the coefficents. Once the update was made, the computer printed the new values.

A requirement of the calibration operation was that both sodium level measurement (LT 40) and pump tank cover gas pressure (PT 115) be calibrated before proceeding with any of the system pressure measurements. This was necessary since they are both used in computing pressure at the sensing port.

Figures 16 and 17 are typical computer printout sheets for a differential pressure transducer and a gage pressure transducer, respectively. The additional data displayed on the gage pressure calibration sheet are used to calculate the sodium pressure at the sensing port.

3. <u>Recommendations</u>

1) As many error-producing circuit components and connections as possible should be eliminated between the transducer signal conditioning devices and the DDAS. The low-level bridge output should go directly to the DDAS for critical measurements.

COEFFICIENT CALCULATION OUTPUT FOR FT-101B
9:59 PM MON., 27 JULY, 1981 REV-810313

	ENG. UNITS MEAN	ENG. UNITS SIGMA	MILLIVOLTS MEAN	MILLIVOLTS SIGMA
FT-101B	6.4841	0.0000	1070.0000	.6432
R-CAL	278.8181	0.0000	1910.0000	.9097
TE-120	700.3597	0.0000	3295.0000	1.2864
DRCAL	272.3340		840.0000	

SEAL TEMPERATURE HP SEAL 0.0 LP SEAL 0.0

	A CONSTANT (PSI)	B COEFF (PSI/MV)
PREVIOUS VALUE	-340.42	.32421
CALCULATED VALUE	-348.97	.32614
% DIFFERENCE	-.62	.60
PRESENT VALUE	-348.97	.32614

	ENG UNITS MEAN	ENG UNITS SIGMA	MILLIVOLTS MEAN	MILLIVOLTS SIGMA
FT-101B	0.0000	0.0000	1070.0000	.6432
R-CAL	273.9550	0.0000	1910.0000	.9097
TE-120	700.3597	0.0000	3295.0000	2.2282
DRCAL	273.9550		840.0000	

SEAL TEMPERATURE HP SEAL 0.0 LP SEAL 0.0

	A CONSTANT (PSI)	B COEFF (PSI/MV)
PREVIOUS VALUE	-348.97	.32614
CALCULATED VALUE	-348.97	.32614
% DIFFERENCE	0.00	0.00
PRESENT VALUE	-348.97	.32614

CALIBRATION CONDUCTED BY SCHMIDT DATE:____________

APPROVAL: __________________ DATE:____________

Figure 16. Typical Coefficient Calculation Output for Differential Pressure Transducer

COEFFICIENT CALCULATION OUTPUT FOR PT-105
9:54 PM MON., 27 JULY, 1981 REV-810313

	ENG. UNITS		MILLIVOLTS	
	MEAN	SIGMA	MEAN	SIGMA
PT-105	11.3396	0.0000	1105.0000	0.0000
R-CAL	82.1396	0.0000	2065.0000	3.4036
PT-115	13.9498	0.0000	1255.0000	2.6521
LT-40	160.7223	0.0000	3285.0000	3.4036
TE-120	701.8478	0.0000	3300.0000	2.5729
DRCAL	70.8000		960.0000	
CPT-105	9.8660			
PSEAL	9.8660			

	A CONSTANT (PSI)	B COEFF (PSI/MV)
PREVIOUS VALUE	-70.154	.07375
CALCULATED VALUE	-71.628	.07375
% DIFFERENCE	-.49	0.00
PRESENT VALUE	-71.628	.07375

	ENG. UNITS		MILLIVOLTS	
	MEAN	SIGMA	MEAN	SIGMA
PT-105	9.8660	0.0000	1105.0000	0.0000
R-CAL	80.6660	0.0000	2065.0000	3.4036
PT-115	13.9498	0.0000	1255.0000	3.2798
LT-40	160.7223	0.0000	3285.0000	2.8766
TE-120	701.8478	0.0000	3300.0000	3.1511
DRCAL	70.8000		960.0000	
CPT-105	10.2325			
PSEAL	9.8638			

	A CONSTANT (PSI)	B COEFF (PSI/MV)
PREVIOUS VALUE	-71.628	.07375
CALCULATED VALUE	-71.630	.07375
% DIFFERENCE	-.00	0.00
PRESENT VALUE	-71.628	.07375

Figure 17. Typical Coefficient Calculation Output for Gage Pressure Transducer

2) During facility modification periods, when their removal does not affect testing operations, the transducers should all be removed and laboratory recalibrated over their operating temperature range.

3) The facility electrical calibration control system should be modified to allow simultaneous activation of all calibration circuits. This would permit a calibration to be performed more rapidly and minimize operator interaction. The present single-unit calibration capability should also be retained for troubleshooting an individual system.

C. FLOW MEASUREMENTS

1. System Description

The sodium flow measurement system in SPTF includes a 16-in. (40.6-cm) venturi flow tube manufactured to RDT C 4-4T. The venturi is preceded by 20 diameters of piping and followed by 5 diameters of piping. Two ΔP transducers, 0-10 psid and 0-50 psid were selected to cover the flow range from 2,000 to 18,000 gpm (0.126 to 1.13 m^3/s). The outputs of both ΔPs were recorded on the DDAS. Flow measurement system accuracy was ±2% of full range.

In series with the venturi flowmeter was a single-path ultrasonic flowmeter and a 16-in. saddle coil (EM) flowmeter. Both of these flowmeters were test articles supplied by ANL for evaluation through calibration, as permitted by the pump test program. Most calibrations were conducted in conjunction with tests for the pump test program.

The relative locations of the flowmeters are shown in Figure 18.

Another flow measurement system provided by ETEC is referred to as the bypass flowmeter. A 1-in. pipe was welded from the inlet tap on the venturi to the throat tap on the venturi, in parallel with the differential pressure measurement. A permanent magnet flow sensor was used to measure flow in the 1-in. bypass line.

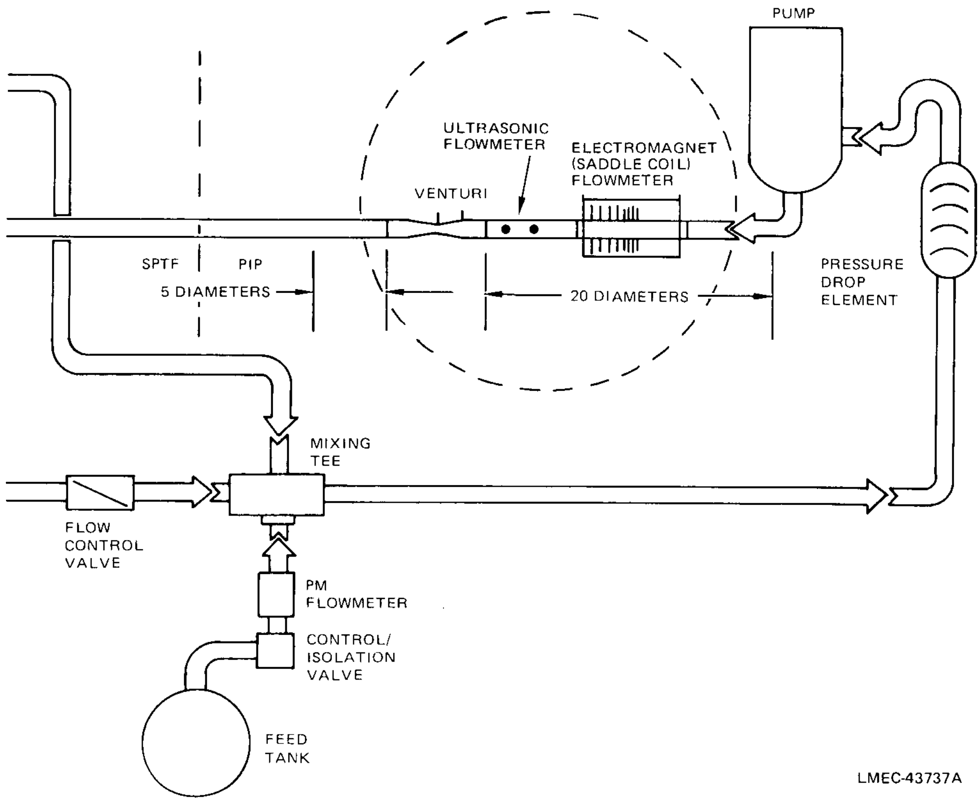

Figure 18. Flowmeter Locations in Main Flow Loop of SPTF

The measured outputs from all these flowmeters were evaluated against the venturi as the reference.

2. Method of Calibration

The venturi flowmeter was originally calibrated, in water, at Alden Research Laboratories, prior to installation at SPTF. This calibration established the discharge coefficient for the basic flow equation. Results of the water calibration are presented in Reference 5.

Venturi flow was calculated by the equation

$$Q = K\sqrt{h}\ (ft^3/s) \qquad \text{(VII-6)}$$

where

$$K = C_d A_o \sqrt{\frac{2_g C_F/\rho}{1 - \beta^4}}$$

C_d = discharge coefficient determined during water calibration

$A_o = \pi/d_o^2 \; (1 + \alpha\Delta T)^2$

g = 32 ft/s^2 (9.806 m/s^2)

d_o = throat diameter = 9.1415 in. (23.2 cm), measured

T = temperature of sodium (^{o}F)

β = 0.59944 (expansion angle 8^o 52')

α = temperature coefficient of Type 304 CRES

C_F = 5.204 lb/ft^2/in. of water

ρ = density of sodium at operating temperature (lb/ft^3) $\left[59.666 - (7.9504 \times 10^{-3}T) - (2.872 \times 10^{-7}T^2) + (8.035 \times 10^{-11}T^3)\right]$

h = pressure head difference (ft) between the upstream pressure and the venturi throat pressure.

The final equation utilized for computing sodium flow rate in gallons per minute was:

$$Q = 4007.5 \times \left[1 + 10^{-5}(T-70)^2\right] \times \frac{h}{\rho} \qquad \text{(VII-7)}$$

Venturi differential pressure transducer calibrations were verified by stopping the pump (thereby establishing zero differential pressure). Transducer zero was verified by applying an electrical simulation on the transducer bridge.

3. Recommendations

It is recommended that sodium test facility flow measurements, particularly for large pipe sizes, include a venturi device.

D. SPTF SODIUM LEVEL MEASUREMENTS

1. System Description

Measurement of sodium level at SPTF was required in the feed tank, the drain tank, and the ISIP-II pump tank. Level measurement at each location was accomplished using an inductive level measuring system. In addition, the sodium level in the pump tank was monitored using a Statham Delta-Pressure system.

The inductive level measuring systems used at SPTF were manufactured by Westinghouse Electric Corp., Industrial and Government Tube Division, Horseheads, New York. Each system consists of a transducer and its associated electronic signal conditioner. The transducer utilizes a single-layer, dual-coil wound sensing element. The coils are single conductor, stainless steel-sheathed, mineral-insulated cable wound in a bifilar manner (two coils wound as alternate turns on a single core). The primary and secondary coils terminate in a five-pin hermetically sealed connector. The transducer is designed to be installed in a facility-supplied 1-in. (2.54-cm) Schedule 40 thimble.

The level measuring system signal conditioner provides constant-current 1.8-kHz excitation to the primary winding of the transducer. The induced secondary voltage from the transducer is conditioned to provide a 4-to-20-mA output proportional to sodium level in the tank. The signal conditioner is of modular construction to allow replacement of individual components.

Signals from the sodium level transducers are provided to the DDAS, a direct inking graphic recorder, a visual indicator, and alarm circuitry.

The block diagram for the pump tank level system (LT 40) is shown in Figure 19 as a typical example of the circuitry. The level system circuitry for the pump tank and drain tank each contains high and low alarms. The feed tank level system circuitry contains high and high-high alarms and low and low-low alarms.

Level measurement system accuracy was ±2% of full range.

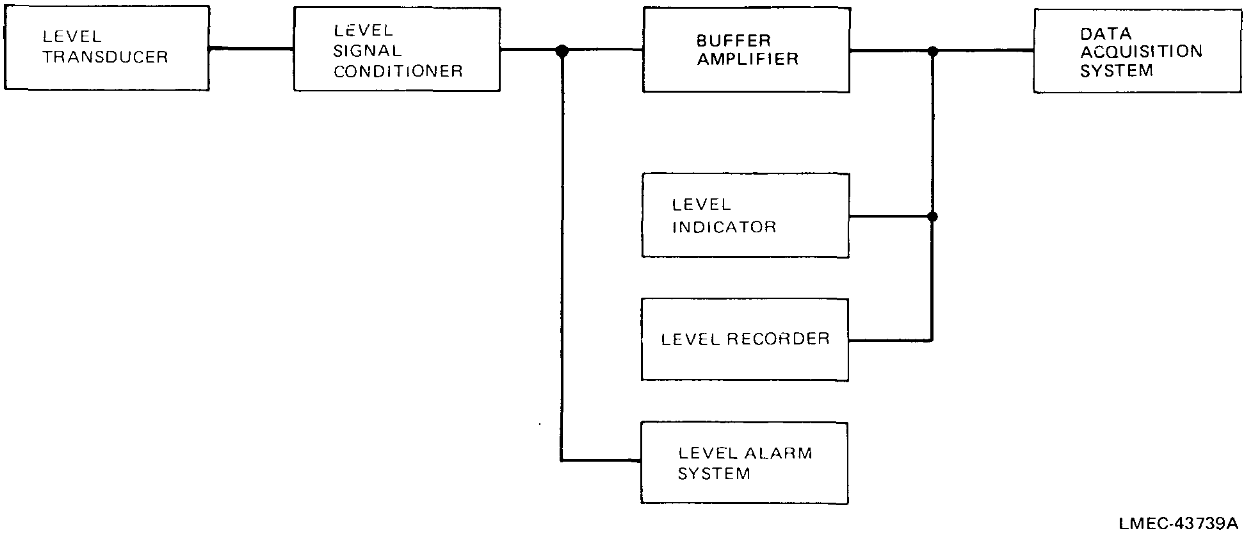

Figure 19. Inductive Level System Block Diagram

2. Calibration Methods

In-place calibration techniques were provided for each of the level measuring systems. The calibration included channelling information from the level transducer to the DDAS scaled data output and the alarm set points. All other devices in the circuit, such as recorders and indicators, were classified as indication-only devices and were not formally calibrated, although they were scaled.

A computer program directed the operator in the steps required to calibrate any of the three level measuring systems by selecting the system to be calibrated from the computer library listing. In the case of the feed and drain tanks, the operator adjusted the sodium level in the vessel to a specified value using a manual dipstick level transducer as a reference. After data had been taken at the first level, the sodium level was adjusted to a second level; using the data from the two set points, the two (A and B) coefficients in the DDAS were computed.

There was no provision for using a manual level transducer as a reference in the pump tank. Calibration was carried out by varying the sodium level between known points in the pump. One of these points was the bottom of the inductive transducer. This point was determined by lowering the sodium level until the output from the inductive system stopped changing. The second calibration point was taken at an elevation of significantly larger internal cross section near the maximum sodium level in the pump tank. This point was determined by filling the pump at a constant flow rate and determining (either manually from a strip chart recorder or automatically from the DDAS) the change in slope of a level-vs-time comparison (Figure 20). All pump tank sodium levels are referenced to the nozzle on the pump tank identified as N5. The reference dimensions used for calibrating the scaling coefficients were determined from Westinghouse Drawing J 689J080 and were analytically corrected for each SPTF operating temperature.

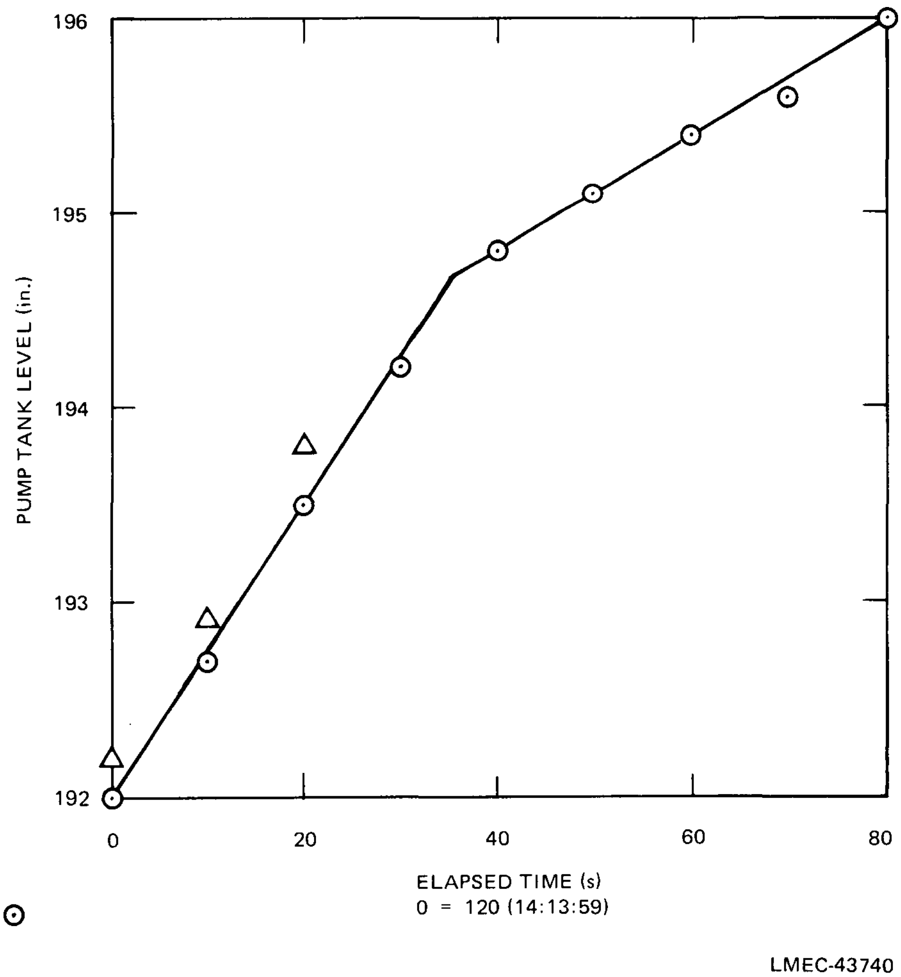

Figure 20. Change in Slope Determination, SPTF Pump Tank at 400°F

During level calibration, the sodium level in the pump tank was lowered at a constant flow rate. The DDAS determined when the output from the inductive unit stopped changing and then directed the operator to increase sodium level in the pump tank at a constant flow rate. The DDAS determined the change in surface area and, from the two reference points, calculated new scaling coefficients. These were presented to the operator with the current coefficients, the newly calculated coefficients, the percent difference, and a question as to whether or not to change the coefficients for future operations of the facility.

Following verification or change of the coefficients, the alarms were calibrated by simulating signals from the level measuring system signal conditioner. This provided the necessary simulated sodium level on the DDAS scaled data output to allow adjusting each of the alarm set points.

3. Recommendations

1) Eliminate as many error-producing effects as possible. Only necessary readout instruments or amplifiers should be included in the circuit from the signal conditioner to the DDAS.
2) Calibration of the measurement systems should be accomplished on a regular interval. Provisions for calibrating the system after significant changes in operating conditions should be provided.

E. BEARING FILM THICKNESS MEASUREMENTS

1. System Description

Proximity measurement systems manufactured by Kaman Sciences were installed in the ISIP-II pump for test in SPTF. They were designed to measure and monitor clearance between the pump shaft and the bearing (sodium film thickness).

The Kaman proximity probe system consists of signal conditioners and sensing probes. The output of the signal conditioner is recorded on the DDAS and the FM analog tape and is paralleled to the alarm computer.

An alarm computer program was developed to calculate the minimum allowable bearing thickness. Outputs of each of the six pairs of proximity probes was sampled by the computer at least 40 times per shaft revolution. The magnitude of the east-west output was squared and added to the square of its matching north-south output. The sum was compared to the square of the bearing clearance limit (75% of the available radial clearance as determined during pump assembly).

The alarm computer displayed on a CRT the location of the shaft relative to the bearing journal in the form of Lissajou patterns. The alarm computer also computed the bearing clearance. If the clearance exceeded a preset limit, an alarm was sounded. A block diagram of the bearing pocket probes is shown in Figure 21. The block diagram for these bearing probes is shown in Figure 22.

2. Method of Calibration

As in FFTF pump testing, the spool and hub flange were clamped, thereby forcing the shaft to swing to the opposite bearing wall. The proximity probes were calibrated with a reference point on the shaft oriented in four different positions 90 degrees apart.

A computer program was developed that multiplexed transducer output and solved the following equation:

$$\frac{(X - S)^2}{a^2} + \frac{(Y - t)^2}{b^2} = 1 \qquad \text{(VII-8)}$$

where

X = output from E-W transducer (mV)
Y = output from N-S transducer (mV)

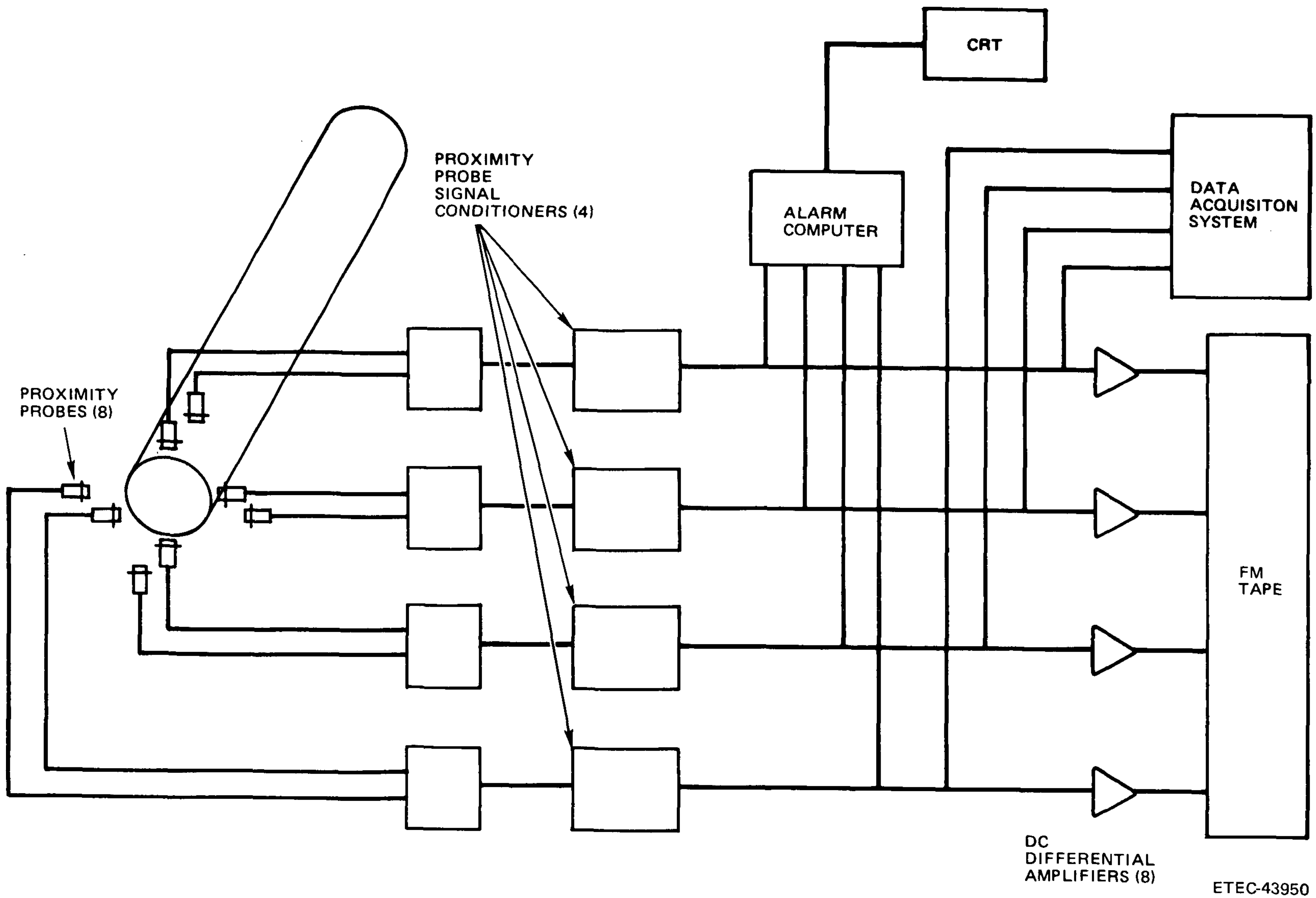

Figure 21. Eddy-Current Proximity Probe Block Diagram, Bearing Pocket Probes

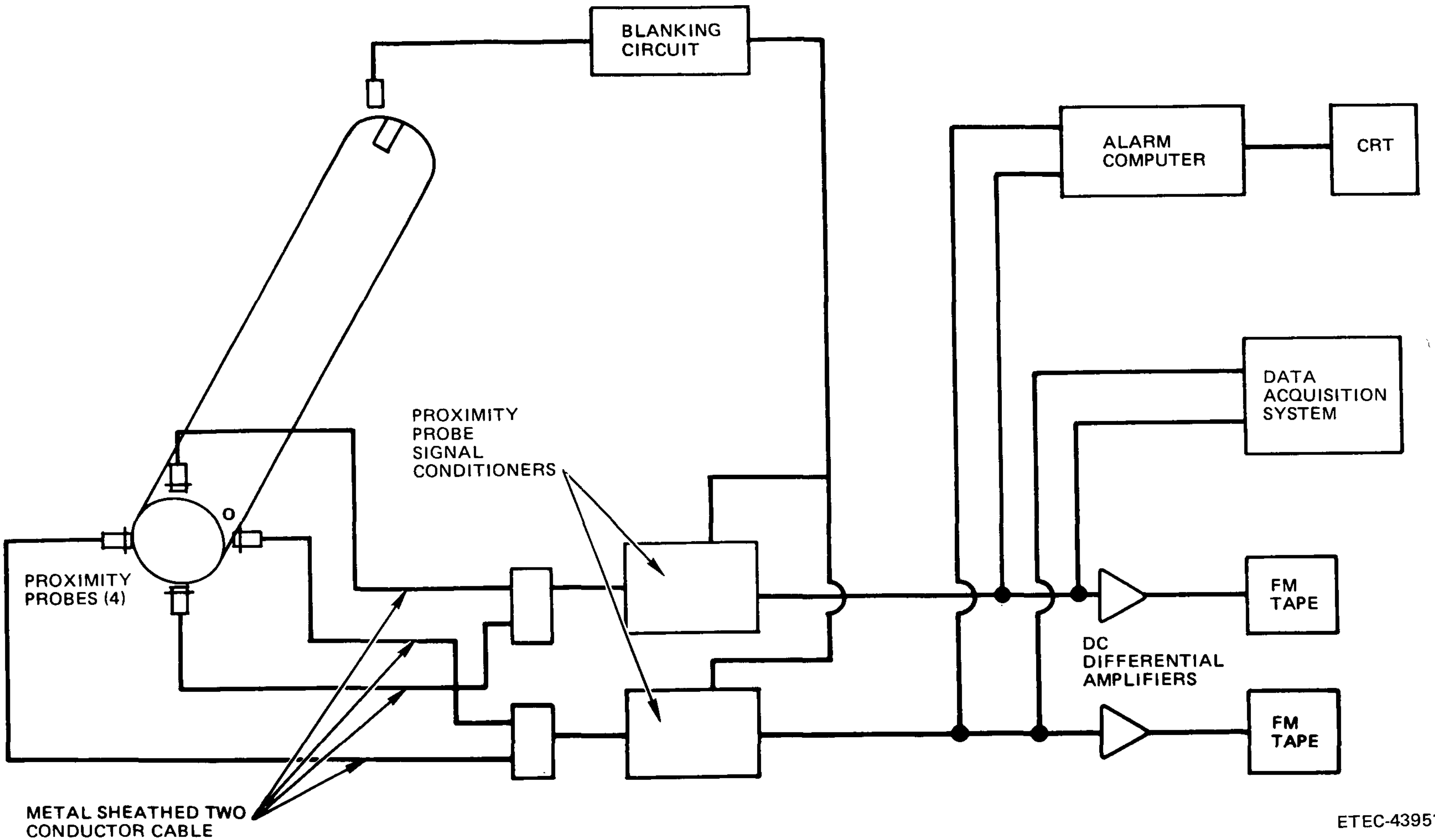

Figure 22. Eddy-Current Proximity Probe Block Diagram, Above-Bearing Probes

a = half axis parallel to E-W (mV)

b = half axis parallel to N-S (mV)

S = ellipse center in E-W direction (mV)

t = ellipse center in N-S direction (mV).

The B and A scaling coefficients were calculated as:

$$B_{E-W} = \frac{K_1}{2a} \text{ (mil/mV)} \qquad \text{(VII-9)}$$

$$B_{N-S} = \frac{K_1}{2b} \text{ (mil/mV)} \qquad \text{(VII-10)}$$

$$A_{E-W} = -S\ B_{E-W} \text{ (mil)} \qquad \text{(VII-11)}$$

$$A_{N-S} = -t\ B_{N-S} \text{ (mil)} \qquad \text{(VII-12)}$$

where

K_1 = diametral bearing clearance as measured at CHCF.

This computation eliminated the uncertainty of clamp location.

Using 5-mil calibration buttons fabricated on the shaft, these bearing proximity measurements continually measured and computed the diametral clearance. By measuring the sum of the two voltage deflections provided by the two 5-mil steps for every revolution, the wall-to-wall clearance was calculated.

Two of the four transducers failed during sodium fill, thereby disabling this measurement (above the bearing) from the outset of the test program. Probes within the bearing pocket provided usable data until all probes failed during the low NPSH testing. At the present time, the probes are not available for failure analysis.

3. Recommendations

Proximity measurement systems have proved to be a valuable on-line measurement and diagnostic tool for pump bearing performance. The Kaman eddy-current proximity measurement systems have provided acceptable data but have not proven to be sufficiently durable at vacuum conditions.

Ultrasonic proximity measuring systems, being developed at ETEC under Contract DE-AM03-76-SF00700, are recommended for future proximity measurements for pump bearing performance.

F. SHAFT-TO-SEAL DYNAMIC MEASUREMENT

1. System Description

Proximity probes were installed to measure the vertical and radial motion of the upper seal and upper seal mating ring surfaces. Figure 23 schematically depicts the location and measuring axis of the 12 probes. The output of the 12 proximity measurement probes was recorded on an analog tape recorder. The

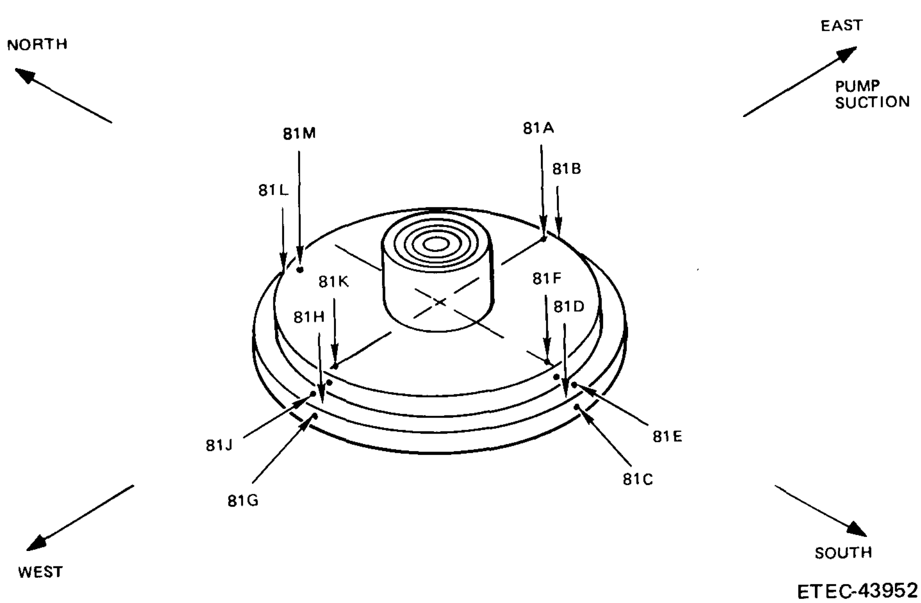

Figure 23. Upper Oil Bearing Proximity Probe Orientation

proximity probe system was comprised of Bently-Nevada proximity sensors (Model 190-00-00-08-18-02), extension cable, proximitors (P/N 115-2800-190), and a dc power supply.

Four probes (Nos. ZE-81A, -81F, -81K, and -81M) measured the vertical motion of the upper seal mating ring. Four probes (Nos. ZE-81B, -81D, -81H, and -81L) measured vertical motion of the upper seal. Two probes (Nos. ZE-81E and -81J) measured the horizontal motion of the upper seal mating ring. Two probes (Nos. ZE-81C and -81G) measured the horizontal motion of the upper seal.

The outputs of the sensors were recorded on a Sangamo Sabre III analog tape recorder.

2. Method of Calibration

Calibration of the shaft-to-seal probes was initiated by establishing the power supply voltage at -18 V ± 0.5 V. The pump shaft was stationary during this calibration period. Initially, all of the probes were set at 60 mils ± 1 mil gap. The input voltage for each of the 12 channels was recorded on the tape recorder. The gap for each of the probes was then set at 20 mils ± 1 mil. These voltages were also recorded. A final gap setting of 40 mils ± 1 mil was established, and the 12 output voltages were also recorded. The probes were left in this position for the test program. The output voltage vs the calibration gap provided a reference to measure relative shaft-to-seal movement during pump testing.

G. PUMP SPEED MEASUREMENT

1. System Description

Pump speed was measured by two basically different systems. One system consisted of a direct-current tachometer generator that was belt driven from the pump drive system. This generator was an integral part of the main motor assembly. The output voltage of the tachometer was reduced through a potentiometer and connected to a high-level DDAS multiplexer channel. The dc tachometer, although reliable, was found to be temperature sensitive. The tachometer generator voltage output per revolution of the shaft varied with changes in ambient temperature.

The second system consisted of a Bently-Nevada proximity measuring system installed next to a pump shaft coupling flange. It generated two pulses each time the pump shaft made a complete revolution. The output from the proximity system was connected to an Anadex calculating scaler adjusted to display pump speed in revolutions per minute. This output display was visual only.

The proximity system output was also connected to an Anadex FM-to-dc converter, which provided an output voltage proportional to the input pulse frequency.

There was some random difficulty in measuring speed over the full range. Therefore, a third speed measurement was introduced. A Hewlett-Packard time-interval counter was utilized to measure pump shaft rotational frequency by sensing the output of the proximity probe. The digital output of the counter was wired directly through a digital interface to the DDAS. The frequency was converted to pump shaft speed in the computer. This speed measurement proved to be the most accurate.

The pump speed measurement system accuracy was ±1% of full range.

2. Calibration Method

The Anadex calculating counter and the Hewlett-Packard counter were calibrated against known frequencies. The output was scaled to read the proper shaft rotational speed on the visual display or DDAS.

The dc tachometer readouts were calibrated by comparing the indicated rpm on the digital counter and adjusting the dc tachometer readouts to agree.

3. Recommendations

The alternating-current pulse-generation speed-measuring system was not susceptible to ambient temperature effects. It is recommended that a pulse counter system be used for speed measurements for performance calculations.

H. SPTF VIBRATION MEASUREMENT

1. System Description

The vibration measurement systems utilized during ISIP-II pump testing served the dual purpose of providing both acceleration information and displacement information. Acceleration data were a direct product of these instrumentation systems. Displacement data were acquired by double integration of the acceleration signal through selected equipment.

Gulton Vibration Monitoring System — A vibration monitoring system manufactured by Gulton Industries, Inc., of Costa Mesa, California, was a primary source of vibration data during pump tests. The Model IV 1839 Gulton system monitors both acceleration and displacement levels. This system is based on four three-channel signal conditioners (P/N 10001123) and four three-channel charge converters (P/N 10001121). A block diagram of the system is shown in Figure 24.

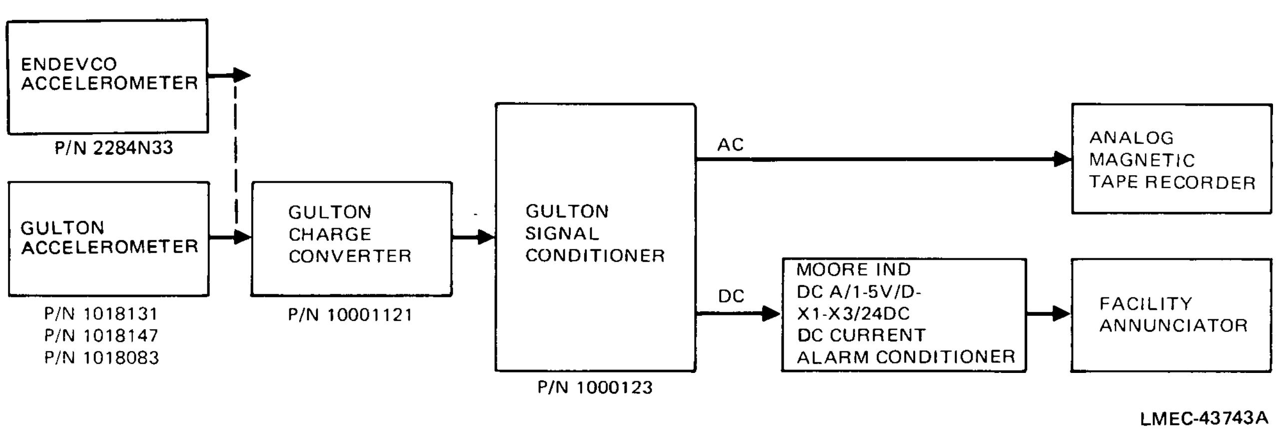

Figure 24. Typical Gulton Vibration Measurement Channel

Gulton accelerometers (P/N 1018131) were used for ambient temperature vibration measurements on the motor stand and bearing housing. For the pump tank nozzle vibration, Endevco accelerometers (P/N N2284N33) were used with Gulton signal conditioning (see Figure 24). This same system was used for FFTF pump Phase B testing in 1977. Table 2 lists the characteristics of the Gulton accelerometer and the Endevco accelerometer.

TABLE 2

ACCELEROMETER CHARACTERISTICS

	Gulton P/N 1018131	Endevco P/N 2284M8
Charge sensitivity	50 pC/g	10 pC/g
Mounted resonance frequency	25 kHz	12 kHz
Charge frequency response	±5%, 3 Hz to 5 kHz	±10%, 100 Hz to 5 kHz
Amplitude linearity	±1% of best straight line	±1% of best straight line
Temperature range	-65 to + 300°F (-54 to 149°C)	-65 to 1400°F (-54 to 760°C)

Note: The acceleration and displacement frequency response are as follows:

Acceleration — 9 Hz to 5 kHz (± 5%) (spec)

Displacement

Filter in — 15 Hz to 500 Hz (spec)

Filter out — 9 Hz to 500 Hz (spec)

The system vibration outputs could be individually monitored by panel meters mounted on the signal conditioner through selection of appropriate pushbutton selectors. The system vibration output signals were also recorded on analog magnetic tape, and the conditioned direct current displacement output signals were selectively used for facility operating alarms or recorded on the facility DDAS.

2. System Calibration Techniques

Piezoelectric Vibration Measurement Systems — The Gulton vibration monitoring system utilized piezoelectric accelerometers. It was impractical to remove the accelerometers from their installations to apply standardized acceleration inputs for calibration; therefore, a calibration of the accelerometers could not be performed after installation. System calibration was restricted to the related signal conditioning equipment. This calibration was performed by disconnecting the accelerometer and injecting a calculated voltage that simulated the accelerometer output signal for an assumed vibration level. The calculated voltage was introduced into the input of the remote charge converter. The resultant system output was monitored at the charge amplifier output.

The calibration signal is generated by applying a signal voltage from an oscillator (1 kHz) in series with a precision capacitor. When implemented, the charge seen by the remote charge converter is:

$$Q = \frac{EC}{1000} \qquad \text{(VII-13)}$$

where

Q = input charge (pC)
E = signal voltage (mV)
C = series capacitor (pF).

When the series capacitor is selected to be 1000 pF and the above equation is rearranged to place signal voltage (E) as the unknown variable, the following equation results:

$$E = Q \qquad \text{(VII-14)}$$

where the input charge (Q) is calculated as the product of the assumed acceleration level and the sensitivity (in pC/g) for the specific accelerometer whose channel is being calibrated. The accelerometer sensitivity is obtained from the manufacturers or other calibration record source. In this way, an exact voltage calibration signal can be calculated for use in system calibration.

Inductive Vibration Measurement System – Two inductive-type accelerometers, Model 1904-109, manufactured by Kaman Sciences of Colorado Springs, Colorado, were mounted on the pump tank nozzle with the three Endevco piezoelectric units. They were capable of responding to vibration frequency down to nearly direct-current level.

3. Vibration Data Analysis

It was intended that analysis of the complex vibration waveforms would normally be performed off-line from analog magnetic tape records. This type of data processing was handled on a Hewlett-Packard Model S451B Fourier analyzer system located in the data management center. To add greater flexibility to pump testing, a real-time spectrum analyzer was also located in the SPTF control room. This device, a Hewlett-Packard Model 3582A spectrum analyzer, was interfaced to the DDAS. Through a relay panel, the DDAS selected one of 11 pump accelerometers to be analyzed. The analyzer output was fed to the DDAS, which plotted the results on the printer-plotter in the control room.

I. SPTF ANALOG MAGNETIC TAPE SYSTEM

1. System Description

While a great number of test measurements could be recorded adequately on the DDAS, other parameters required a higher frequency response system because of their dynamic nature. For high-response requirements, analog magnetic tape recorders were employed.

The type of magnetic tape recorders that were used could be configured for either the FM or the direct-recording mode. Most parameters were recorded in the FM mode to take advantage of its superior accuracy. However, selected parameters were recorded in the direct mode to increase system frequency response. Frequency response is significantly greater in the direct mode.

Three Bell and Howell recorders (Model CPR-4010) and a Sangamo recorder (Model Sabre III) were used. Each had 14-data-channel recording capability. When operated in the FM mode, these tape recorders provided a linear frequency response from direct current to 1.25 kHz at 3-3/4 in./s tape speed and direct current to 5.0 kHz at 15 in./s tape speed.

As a means of identifying data, voice annotation was applied to a voice channel on the tape. A written tape event log was maintained in which tape footage and time of day were entered for the beginning of each test event. The date and time were written on tape Channel 14 in the IRIG B time code format. The tape event log sheet and a tape channel identification sheet were permanently stored in each tape reel box to ensure proper identification of information during data processing.

Analog Magnetic Tape Operating Procedure — The previously described magnetic tape recorders were used in various ways to collect data. At times, the pump was not being operated in an actual test mode because of overriding facility operating considerations. In these instances, the analog magnetic tape recorders were operated to record short data slices at periodic intervals of 1 h or more. Similar data acquisition was used for long-duration steady-state testing. The recorders were operated continuously to document transient pump operating modes.

2. Analog Magnetic Tape Calibration Procedure

Calibration signals were provided to ensure accurate handling of test data recorded on analog magnetic tape. The calibration system consists of an audio oscillator, a counter or frequency meter, and a digital voltmeter. The calibration voltage is set at 1 V rms at 1000 Hz. A relay is used to switch the tape recorder impact from the data input to the calibration voltage input. Detailed calibration procedures are specified in ETEC Procedure 462-OP-600, "SPTF Analog FM Tape Calibration Operation Procedure."

VIII. TEST METHODS

Performance tests of the ISIP-II pump were conducted in a manner similar to those previously run on the FFTF prototype pump.[5] However, thermal transient tests were not performed with the ISIP-II pump. The requirements for the ISIP-II tests are presented in the Request for Test (RFT) of Reference 6.

A. SODIUM MELT AND HEATUP

Melting of sodium in the drain and feed tanks and dry preheat of the main flow loop (MFL) and pump tank were accomplished by means of electrical trace heaters on the tanks and piping. Heatup to 700°F (371.1°C) and wetting were accomplished by pump rotation at ∿600 rpm. Melting of sodium in the drain and feed tanks was begun on March 13, 1981.

The main flow loop, purification system, vent lines, and other sodium system lines were also dry preheated to 400°F (204.4°C) by means of electrical heaters.

Dry preheat of the pump tank was initiated on April 14, 1981 — a day ahead of schedule. It required 180 hours to bring the pump bearing temperature to 400°F. Figure 25 shows typical pump tank and bearing temperatures during the preheat period. The rate of heatup was controlled so it would not exceed 10°F (5.6°C) per hour. Pump breakaway torque was measured at 1-h intervals during the preheat period. Pump shaft breakaway torque values were compared to ambient temperature breakaway torques. The purpose of frequently checking shaft breakaway torque was to ensure that pump shaft binding could be detected and corrected early. Neither shaft binding nor unusually high shaft breakaway torque was encountered at any time during the test program. A plot of the average pump shaft breakaway torque during the dry preheat period is also shown in Figure 25.

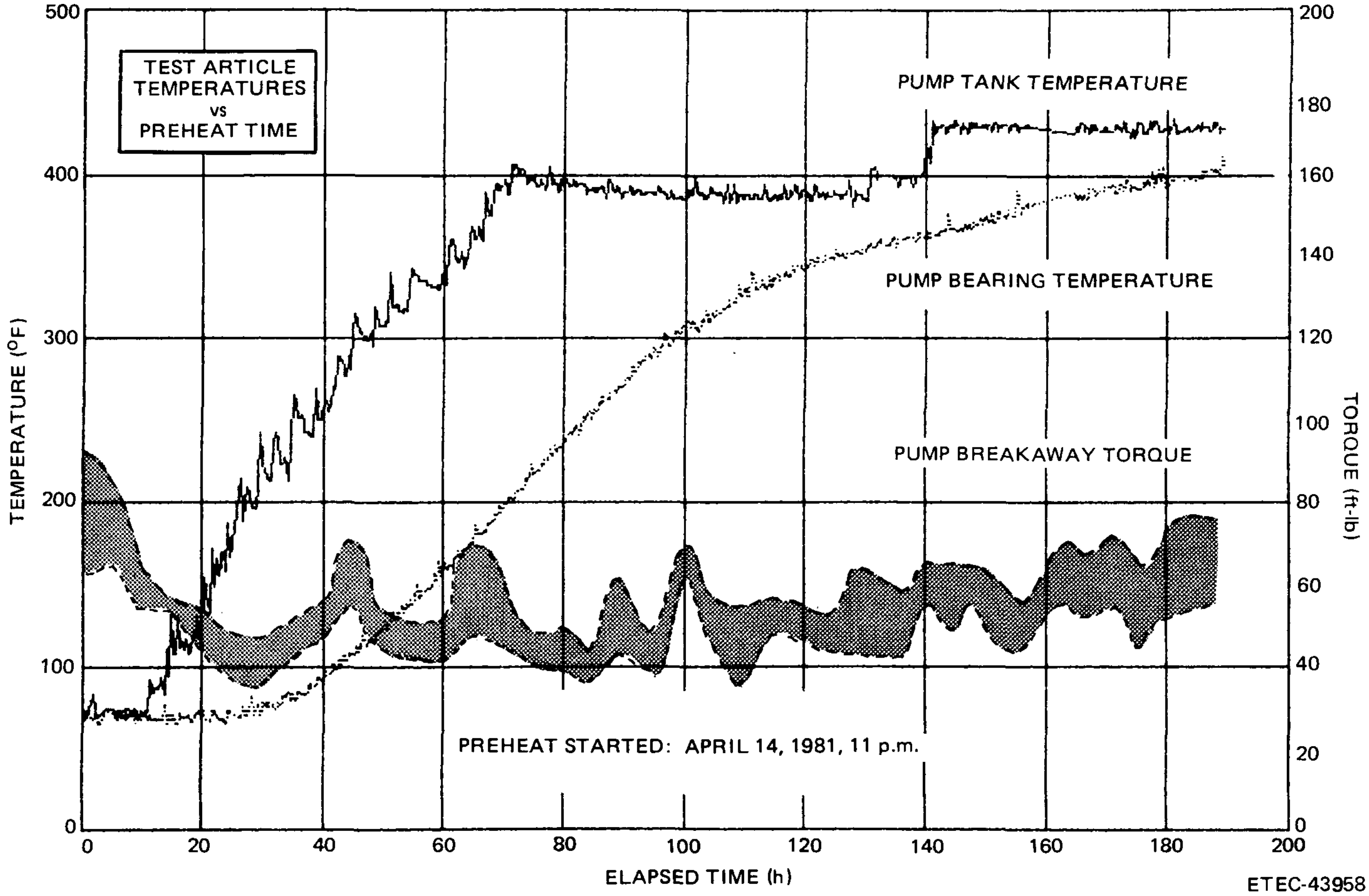

Figure 25. Test Article Preheat History

B. TESTING APPROACH

Testing proceeded from less severe to increasingly severe conditions. Speed scans and flow scans were performed at discrete temperature levels from 700^{O}F (371.1^{O}C) to 1050^{O}F (565.6^{O}C). A cavitation "head drop limit" test was performed at 950^{O}F (510^{O}C). Endurance runs at 1050^{O}F (565.6^{O}C) and 950^{O}F (510^{O}C) at NPSH of 29 ft (8.84 m) were also performed.

Increase of sodium temperature in the flow loop was accomplished by heat input due to pump work. The sodium temperature was reduced by slowing the pump speed and by utilizing the facility sodium cooler.

Pump head, flow, electrical power consumption, and efficiency were measured for all test conditions. Several of the critical pump and facility operating parameters were displayed on a TV screen and continuously updated for the convenience of the operators.

C. SPEED SCANS

Speed scan tests were run by varying the pump speed from ~600 rpm (minimum main motor speed) to the design speed of 1110 rpm in specified increments while maintaining relatively constant flow impedance in the test flow loop.

Constant speed at any operating point was maintained by means of a closed-loop feedback controller incorporating a liquid rheostat system. The test conditions were allowed to stabilize for a minimum of 15 min at each speed plateau. A typical plot of pump speed as a function of time is shown in Figure 26.

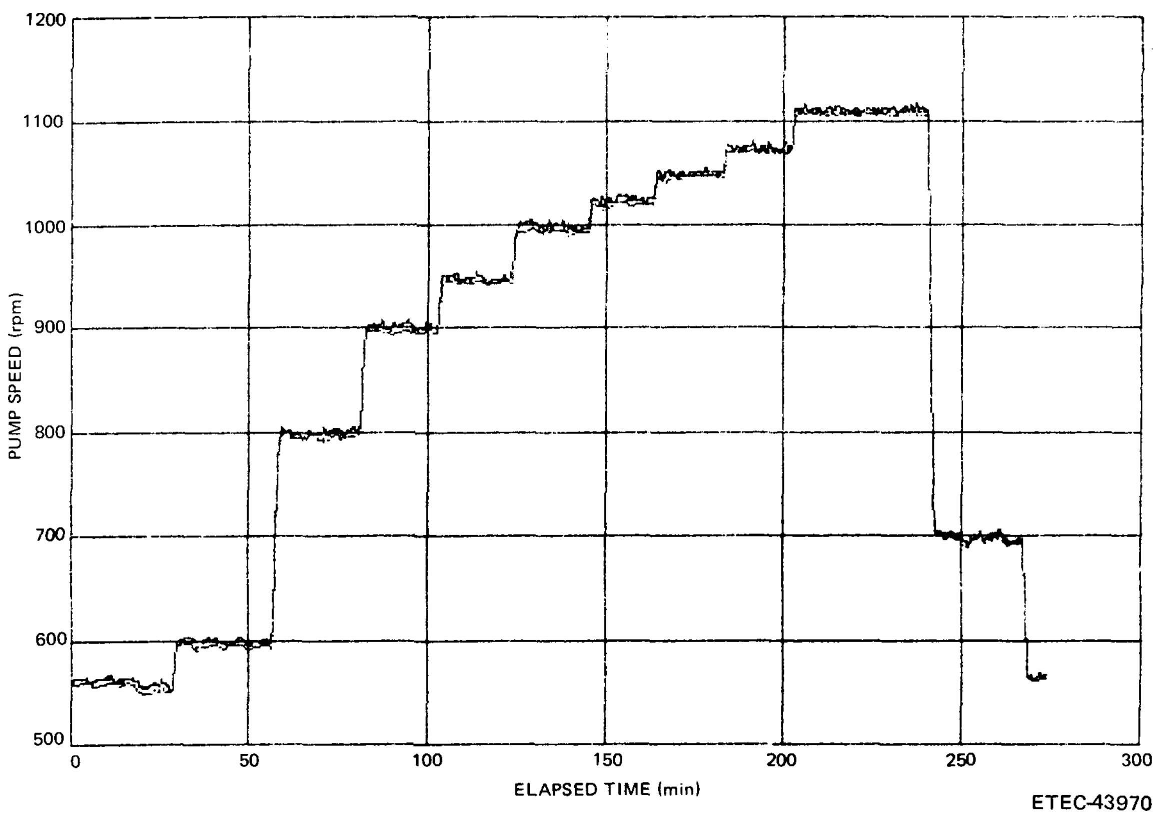

Figure 26. Typical Pump Speed Scan Time History

Figure 26 is the speed-vs-time plot for the 850^{o}F (459.4^{o}C) speed scan. For this test only, the 700-rpm step was skipped on the speed upramp to expedite maintaining sodium temperature. The 700-rpm point was picked up after completing the speed upramp.

Speed scans were run at two system resistance values, R4 and R5. System resistance is defined[6] as a function of the flow divided by the pump speed (Q/N) as follows:

Resistance	Flow/Speed (Q/N)
R4	$\frac{14500 \text{ gpm}}{1110 \text{ rpm}} = 13.063 \text{ gal/rev} \left(\frac{0.9148 \text{ m}^3\text{/s}}{1110 \text{ rpm}} = 8.24 \times 10^{-4} \text{ m}^3\text{/rev}\right)$
R5	$\frac{18000 \text{ gpm}}{1110 \text{ rpm}} = 16.216 \text{ gal/rev} \left(\frac{1.1356 \text{ m}^3\text{/s}}{1110 \text{ rpm}} = 1.023 \times 10^{-3} \text{ m}^3\text{/rev}\right)$

Changes in system resistance were accomplished by adjusting five butterfly valves in the main flow loop. The location of the MFL butterfly valves is shown schematically in Figure 4.

D. FLOW SCANS

Flow scans (seven points) were run at sodium temperatures of 700^{o}F (371.1^{o}C) and 950^{o}F (510^{o}C). The flow rate was varied in discrete steps from ∿13800 gpm (0.8706 m^3/s) to 18000 gpm (1.1356 m^3/s) by use of the facility butterfly valves while maintaining pump speed constant at 1110 rpm.

A four-point flow scan at 950^{o}F (510^{o}C) was also performed to calibrate the system resistance characteristics prior to performing the cavitation test. These data were used to predict the cavitation test initial flow rate.

The general technique of performing a flow scan was to set the flow-divided-by-speed variable (Q/N) to the desired set point at a speed of 750 rpm. The speed was then increased to 1110 rpm to take data. The speed was then reduced to

750 rpm to set the new value of Q/N and the procedure repeated for all values of Q/N. This technique was employed to avoid operating the facility butterfly valves at high flow conditions. A typical plot of pump speed and flow rate for a flow scan is presented in Figure 27. The data shown in Figure 27 are for the 700^{0}F (371.1^{0}C) flow scan.

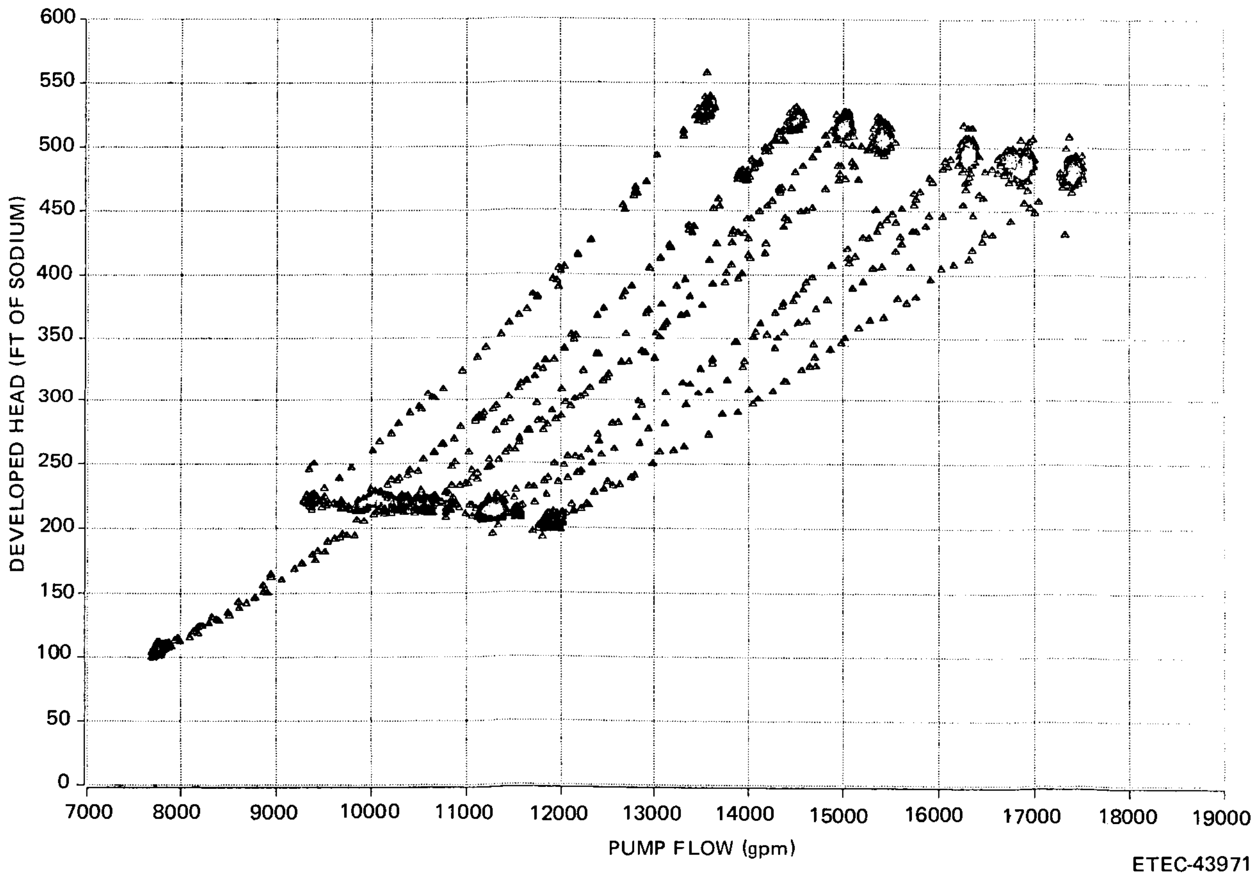

Figure 27. Typical Flow Scan, Head vs Flow Rate

E. CAVITATION TEST

One cavitation performance test was performed at a sodium temperature of 950^{0}F (510^{0}C) and a pump speed of 1110 rpm. The purpose of the test was to determine the net positive suction head at which the developed head across the pump will be reduced from the noncavitating head by 3%.

The first step in performing the cavitation test was to determine the initial flow rate at the start of the cavitation test such that the final flow rate at the 3% head drop limit was equal to 14,500 gpm (0.9148 m^3/s). The initial flow rate was determined by the procedure described in Appendix B.

The noncavitating head was established by running the pump at the initial cavitation flow rate at a sodium temperature of 950^oC (510^oC) and a pump speed of 1110 rpm. The pump tank sodium level was reduced to 48 in. (121.9 cm) from 125 in. (317.5 cm) above the impeller for the cavitation test. The purpose of lowering the sodium level was to reduce the pump tank vacuum requirement. The pump tank pressure was then reduced gradually by means of a vacuum pump until cavitation occurred. The critical pump parameters (Q/N and the calculated NPSH referenced to inducer inlet) were displayed in graphic format on a TV screen for constant monitoring during the cavitation test. The results of the cavitation test were used to establish the NPSH value for the 950^oF (510^oC) endurance run.

F. ENDURANCE RUNS

Two separate endurance runs were performed. The first was performed at a sodium temperature of 1050^oF (565.6^oC) and an NPSH of 60 ft (18.3 m) for 48 h. The second run was performed at a sodium temperature of 950^oF (510^oC) and an NPSH of 29 ft (8.8 m) for 941 h.

1. <u>48-Hour Endurance Run 1050^oF (565.6^oC)</u>

A speed scan at R4 loop impedance was performed at 1050^oF (565.6^oC) to verify satisfactory pump operation at a high temperature.

An endurance run at the following conditions was then performed to requalify the pump shaft for 1050^oF (565.6^oC) operation at FFTF:

NPSH	60 ± 2 ft (18.3 ± 0.6 m)
Sodium temperature	1050 ± 10°F (565.6 ± 5.6°C)
Flow rate	14,500 ± 200 gpm (0.9148 ± 0.0126 m^3/s)
Speed	1110 ± 5 rpm
Duration achieved	48.1 h

2. Reduced NPSH Endurance Run at 950°F (510°C)

The 950°F (510°C) endurance run exposed the pump to extended operation at 155% NPSH margin over the critical NPSH. The purpose of the run was to demonstrate that the pump would not sustain detrimental effects from operation at reduced NPSH.

The cavitation test provided data that the critical NPSH was 11.3 ft (3.44 m) at the 3% head drop limit condition.

The revised Request for Test of Reference 7 specifies that the 950°F (510°C) endurance run be performed at an NPSH of 155% margin over the critical NPSH. The endurance run NPSH is then:

$$NPSH_{endurance} = (2.55)_{margin} \times (11.3)_{critical\ NPSH} = 29 \text{ ft } (8.84 \text{ m})$$

The test conditions for the reduced NPSH endurance run are listed below:

NPSH	29 ± 2 ft (8.84 ± 0.61 m)
Sodium temperature	950 ± 10°F (510 ± 5.6°C)
Flow rate	14,500 ± 200 gpm (0.9148 ± 0.0126 m^3/s)
Speed	1110 ± 5 rpm
Duration achieved	942.3 h*

*Total duration achieved: 941 h at NPSH = 29 ft (8.84 m) and 1.3 h during cavitation test (NPSH less than 29 ft).

The critical test conditions of NPSH and Q/N were continuously displayed on a TV monitor for the convenience of the operators. A typical example of the parameter box display is shown in Figure 28. Several critical pump operating parameters were continuously displayed on a TV screen for the convenience of the operators. A typical parameter display is shown in Figure 29.

G. PROCEDURES

1. Test Procedures

Test procedures were prepared to control and document the ISIP-II test activity in order to satisfy the test requirements of the Request for Test (RFT), Reference 6. The test procedures were reviewed and approved by ETEC Test Engineering, Operations, and Quality Control and by the AI-ESG test requestor.

An index and abstracts of the test procedure used for the ISIP-II test program are presented in Reference 8.

2. Test Article Assembly/Disassembly Procedures

Procedures were prepared by ETEC to direct the step-by-step assembly and disassembly of the test article. The procedures were based on the FFTF operations and maintenance manual[1] and the ISIP addendum.[2] A list of the test article assembly/disassembly procedures is presented in Table 3.

H. PRECAUTIONS AGAINST PUMP BEARING SEIZURE

Several operational precautions were taken to avoid pump bearing seizure or to prevent excessive damage in the event that bearing seizure did occur. It should be noted, however, that there were no bearing problems encountered during the ISIP-II test program. A brief description of the various precautions follows.

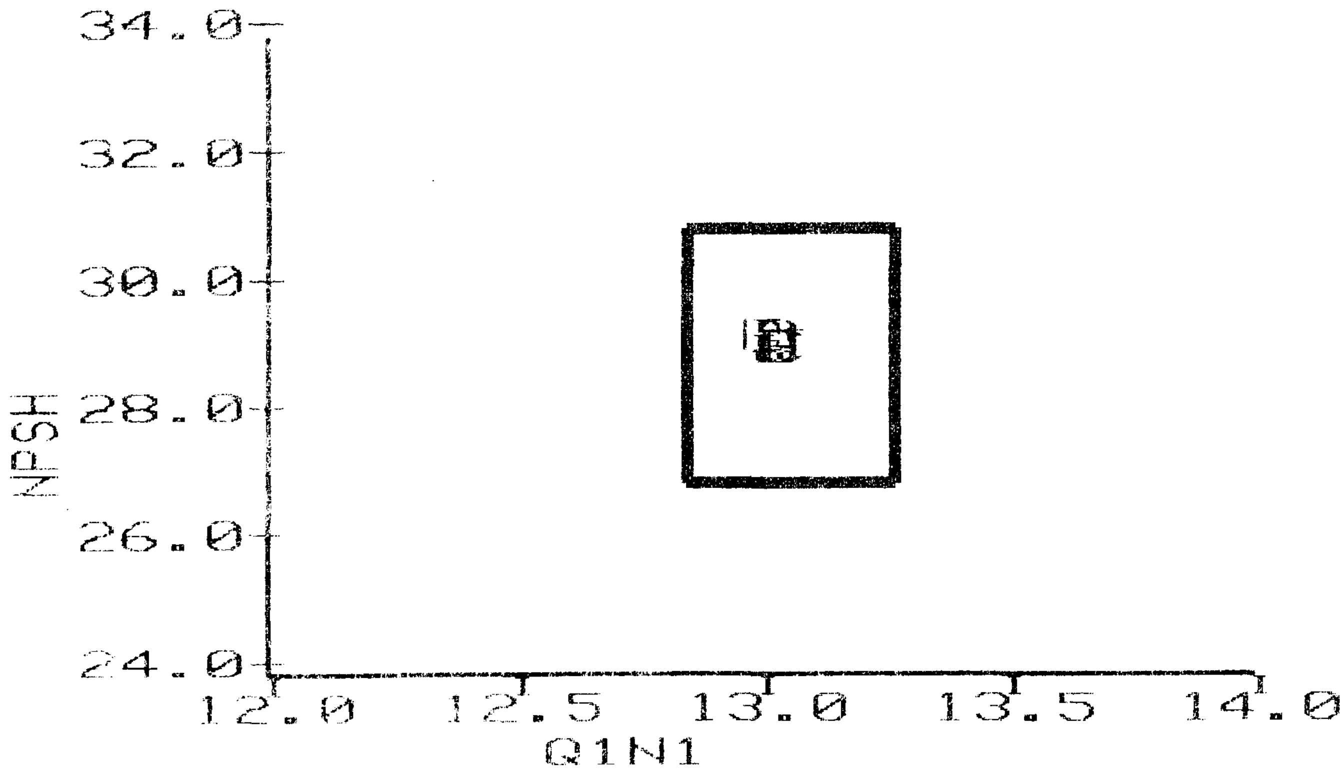

Figure 28. SPTF Operating Parameter Box Display

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SE-HP	587.400	SE-47	586.642
JE-75B	560.871	IE-74B	97.260
FT101AM	7554.634	FT101BM	7625.364
LT-40	131.835	LT-42	127.028
TE-119	949.858	TE-120	952.764
PT-113B	6.565	PT-115	6.564
PT-105	55.563	PT-111	12.531
PT-202	17.286	PT204	29.828
TE-02A	948.404	PT-405	55.606
FE-404	11.850	TE-409	247.644

Figure 29. Typical Critical Parameter Display

TABLE 3

LIST OF ISIP-II ASSEMBLY AND DISASSEMBLY PROCEDURES

Procedure No.	Title
Assembly Procedures	
AP-39-PP-062	Bearing Support Assembly — Instrumentation
AP-39-PP-063	Upending Hydraulics Assembly and Bellows Installation
AP-39-PP-064	SP/SC Upending and Storage
AP-39-PP-065	Trial Fitup of Diffuser Assembly
AP-39-PP-066	Pump Shaft Assembly
AP-39-PP-067	Assembling SP/SC to Pump Shaft Assembly
AP-39-PP-068	Lower Seal Assembly
AP-39-PP-069	Installation of Lower Seal Assembly
AP-39-PP-070	Shaft Alignment Check
AP-39-PP-071	Installation of Thrust Bearing Assembly and Upper Seal
AP-39-PP-072	Upper Seal Assembly
AP-39-PP-073	Installation of Bearing Oil Supply Hardware
AP-39-PP-074	Prepare for Assembly of Internals to Hydraulics
AP-39-PP-075	Upper Internals Lift — Assembly Stand to Storage Stand
AP-39-PP-076	Internals Lift Storage Stand to Pump Assembly Stand
AP-39-PP-077	Assembly of SP/SC to Hydraulic Assembly
AP-39-PP-078	Motor Coupling Installation — Pump Shaft
AP-39-PP-079	Internals Instrumentation Assembly
AP-39-PP-080	Installation of Thermal Baffles
AP-39-PP-081	Pump Transfer from CHCF to SPTF
AP-10-PP-007	Motor Installation
AP-10-PP-008	SP/SC Shot Loading
Disassembly Procedures	
AP-10-PP-009	Disassembly of Shaft Seal and Bearing Assembly
AP-10-PP-010	Prepare for Removal of Pump Internals
AP-39-PP-082	Disassembly of Hydraulics from SP/SC
AP-39-PP-083	Disassembly of SP/SC
AP-39-PP-084	Impeller and Bearing Support Assembly from Shaft
AP-39-PP-085	Disassembly of Thermal Baffles and Instrument Leads
AP-39-PP-086	Disassembly of Lower Seal Assembly
AP-39-PP-087	Disassembly of Upper Seal Assembly
AP-39-PP-088	Transfer of Pump Internals to Cleaning Tank
AP-39-PP-089	Bag Installation Internals Transfer to Clean Tank
AP-39-PP-090	Pump Transfer Cleaning Tank to A/D Stand
AP-39-PP-091	Disassembly of Bearing and Bearing Support Assembly
AP-39-PP-092	Disassembly of Hydraulics and Bellows Assembly

1. <u>Pump Tank L-Delta-T</u>

The pump tank was instrumented with 56 thermocouples on the external skin. These were located over both the heated and unheated regions of the tank. The measured delta-temperature and tank length between thermocouples was integrated over the instrumented surface to determine whether the tank was being unevenly heated. Uneven heating of the pump tank has the potential to cause tank distortion, resulting in binding of the pump shaft. Monitoring of the computed pump tank L-Delta-T values was especially critical during the dry preheat operation before loading sodium into the tank. After sodium was loaded into the pump tank, the sodium itself was a good heat transfer medium, resulting in uniform tank skin temperature.

A description of the L-Delta-T calculation techniques and a sample on-line printout of the calculations are presented in Appendix C.

2. <u>Pump Bearing Proximity Probes</u>

Proximity probes installed at the pump shaft bearing provided a means of measuring the bearing film thickness. The output of the proximity probes was displayed on CRTs and provided to the alarm computer.

An alarm was sounded if the bearing orbit exceeded 75% of the bearing gap. The 75% bearing orbit was also displayed on the CRTs for visual reference.

A complete description of the bearing proximity system is presented in the Instrumentation Description section.

3. <u>Motor Coastdowns</u>

Main motor coastdowns at trip or scheduled shutdowns were monitored to detect any significant difference in time to coast from 600 rpm to 200 rpm. These are arbitrary speeds but provided a reference. The upper speed, 600 rpm, was chosen because the pump speed was at least 600 rpm for almost every trip or scheduled shutdown. The lower speed, 200 rpm, was chosen because it was easier to determine the 200-rpm point from a speed-vs-time plot than it was to determine the pony motor speed or full stop of the pump. A typical main motor coastdown time history is shown in Figure 30. The approximate time to coast from 600 rpm to 200 rpm was 17 sec. There was no significant deviation from the average coastdown time during the test program.

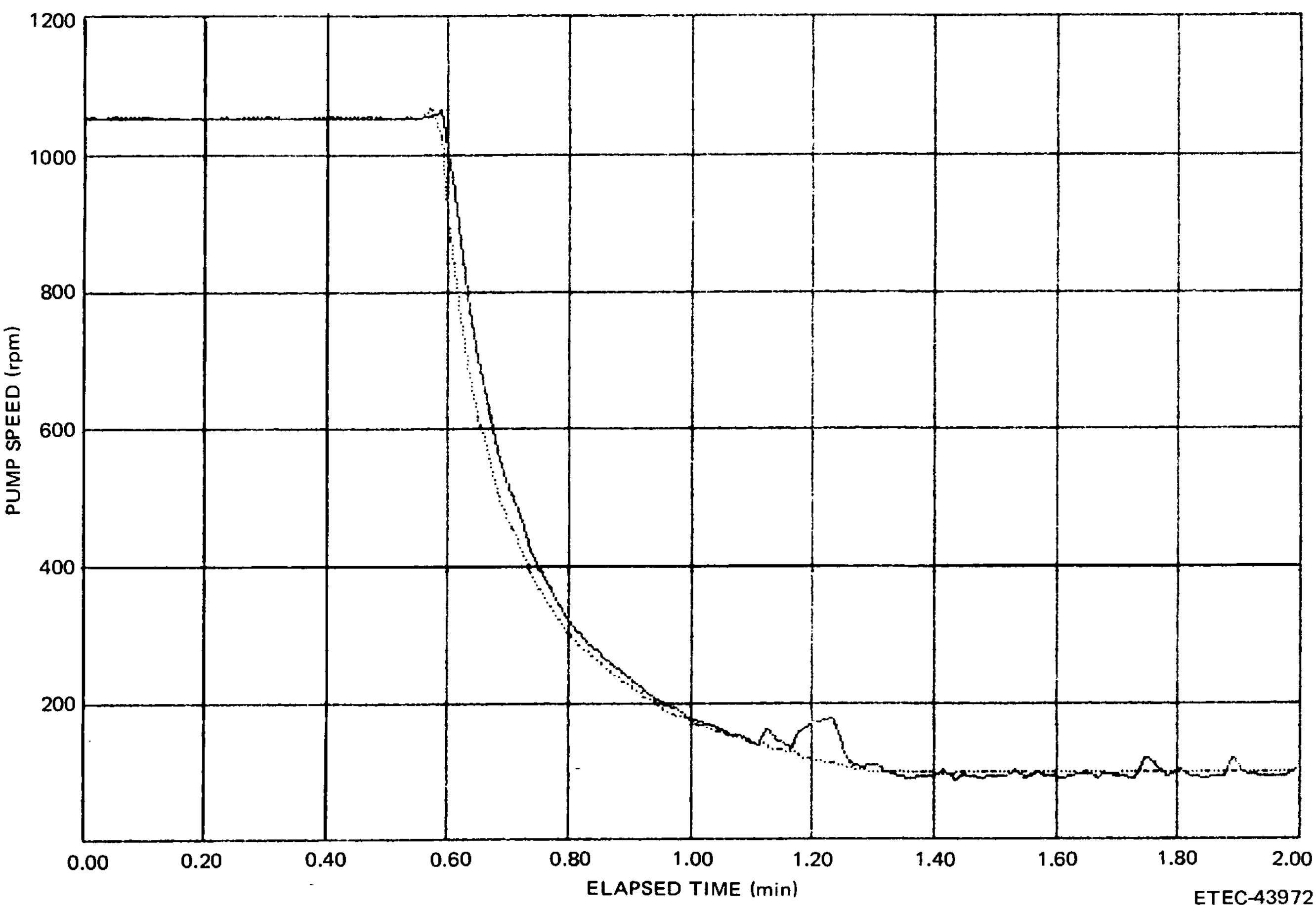

Figure 30. Typical Main Motor Coastdown Plot

The time to coast down from pony motor speed to full stop was also measured periodically by means of an observer using a stopwatch. The stopwatch technique was used because the speed-measuring equipment did not produce reliable data at speeds near zero. The average coastdown time from pony motor speed to full stop was ~39 sec. There was no significant deviation from the average coastdown time during the test program.

4. Pump Shaft Breakaway Torque Checks

It was standard practice during the ISIP-II test program to measure the pump shaft breakaway torque every time the pump was stopped. The breakaway torque was taken each time with the shaft positioned at every 45 degrees. The breakaway torque never exceeded 1.25 times the pretest ambient temperature torque of ~80 ft-lb (108.5 N·m).

5. Power Measurement

The alarm computer provided a means of continuously comparing the measured main motor power against a computed value based on the pump operating conditions. Audible and visual alarms were provided to warn of an impending trip.

The equation for computed power, against which the measured power was compared, was basically the same as that used for FFTF testing in 1977. The only difference was that the computed power equation was adjusted upward 10%. This adjustment was made to compensate for the higher power requirements of the ISIP-II pump due to the higher head produced.

The alarm computer power comparison was backed up with a plant protection system fixed trip point set to 2500 kW for protection in the event of alarm computer failure.

IX. DISCUSSION

The original Request for Test (RFT) of Reference 6 was modified to change the test requirements for cavitation performance tests. The basic RFT changes consisted of monitoring the MFL for cavitation noise and minor operational changes. These changes are documented in Reference 9.

Cavitation noise measurements were made during the cavitation critical NPSH test using an Argonne National Laboratory (ANL) hydrophone and an AI-ESG acoustic emission detector.

Cavitation noise monitoring tests were also performed during subsequent tests by representatives from the United Kingdom Atomic Energy Agency (UKAEA). The NPSH was only reduced to 29 ft (8.84 m) for the UKAEA tests, rather than to the critical NPSH of 11.3 ft (3.44 m) as was done for the cavitation critical NPSH test. Additional special instrumentation provided by UKAEA was used for these cavitation noise monitoring tests.

Operational changes requested[9] were: (1) Testing at maximum NPSH was raised to 90 ft (27.43 m) (formerly 60-ft (18.29-m) NPSH); (2) stabilization time at each specified NPSH level was changed from 10 min to "the time required for noise measurement to stabilize"; and (3) endurance testing at 950^{o}F was changed to 155% margin over the critical NPSH value, rather than 100% margin. The critical NPSH value was that value determined during the cavitation critical NPSH test.

A. CHRONOLOGY OF EVENTS

An overview of the chronology of test activity is presented in Table 4 and Figure 31. Four basic types of tests (speed, scans, flow scans, cavitation tests, and endurance runs) at six discrete sodium temperature levels were performed. The test matrix is shown in Table 5.

TABLE 4

ISIP-II PUMP TEST CHRONOLOGY OF EVENTS
(Sheet 1 of 2)

Day	Event
02/19/81	Pump internals installed into pump tank
02/22-23	Seventeen drums of shot loaded into pump tank shot cavity
04/14	Initiated pump tank preheat
03/05	Installed drive motor onto pump
05/19	Initial sodium load (400°F) to MFL. Leak at flow venturi discovered. Emptied MFL and repaired leak.
05/26	Started initial MFL sodium flush
06/05	Initiated pony motor rotation of pump
	Initiated main motor rotation of pump
06/13	Completed wetting of pump and facility system at 700°F sodium temperature
06/16-21	Performed 700°F R4 Speed Scan 1
06/19-20	Performed 700°F R5 speed scan
06/20	Performed 700°F flow scan
06/21	Performed 750°F R4 speed scan
06/23-24	Performed 850°F R4 speed scan
06/28	Performed 950°F R4 Speed Scan 1
06/28-29	Performed 950°F R5 speed scan
06/29	Performed 950°F R4 Speed Scan 2
06/30	Performed 950°F flow scan
07/02	Performed 950°F cavitation calibration flow scan
07/02-03	Performed cavitation test
07/03-05	Initiated endurance run at NPSH = 29 ft, speed - 1110 rpm, flow = 14,500 gpm
07/08	Performed 1000°F R4 speed scan
07/09-10	Performed 1050°F R4 speed scan
07/10-12	Performed 48-h duration run at 1050°F
07/12	Returned to endurance run conditions at NPSH = 29 ft
07/15	Performed 950°F R4 Speed Scan 3
07/16	Returned to endurance run conditions at NPSH = 29 ft
07/21	Replaced a section of pump tank line. Reduced shaft seal purge. Restarted endurance run at NPSH = 29 ft.

TABLE 4

ISIP-II PUMP TEST CHRONOLOGY OF EVENTS
(Sheet 2 of 2)

Day	Event
07/25	Sodium leak discovered in purification system. Reduced speed to pony motor speed and repaired leak.
07/27-28	Performed 700°F R4 Speed Scan 2
07/28	Returned to endurance conditions at NPSH = 29 ft
08/07	Utilized Hewlett-Packard time interval counter to measure shaft speed. Still on endurance run at NPSH = 29 ft.
08/11	Increased NPSH to 86 ft (N = 1110 rpm) for UKAEA cavitation listening test. Returned to endurance run at NPSH = 29 ft.
08/12	Performed UKAEA cavitation listening test at 690 rpm, NPSH excursion. Returned to endurance run at NPSH = 29 ft.
08/13	Completed UKAEA cavitation listening test at minimum main motor speed. Returned to endurance run at NPSH = 29 ft.
08/25	Removed Hewlett-Packard counter used for speed measurement. Partially completed HEDL coastdown tests. Returned to endurance run conditions at NPSH = 29 ft.
08/26	Partially completed HEDL coastdown tests. Returned to endurance run conditions at NPSH = 29 ft.
08/27	Completed HEDL coastdown tests and returned to endurance run conditions. Terminated endurance run at midnight. Accumulated 942.3-h endurance run duration.
08/28	Begin sodium system cooldown
08/29	Perform ANL flowmeter tests at 400°F. Perform HEDL coupled main motor noise test.
08/30	Perform ANL flowmeter tests at 600°F. Drain sodium system.
08/31	Perform HEDL uncoupled main motor noise test.

Total Operating Time	
Pony motor only operation	109.4 h
Main motor operation	1759.8 h
Including:	
950°F endurance run (NPSH = 29 ft)	941.0 h
Cavitation (NPSH <29 ft)	1.3 h
Total	942.3 h
1050°F endurance run (NPSH = 60 ft)	48.1 h

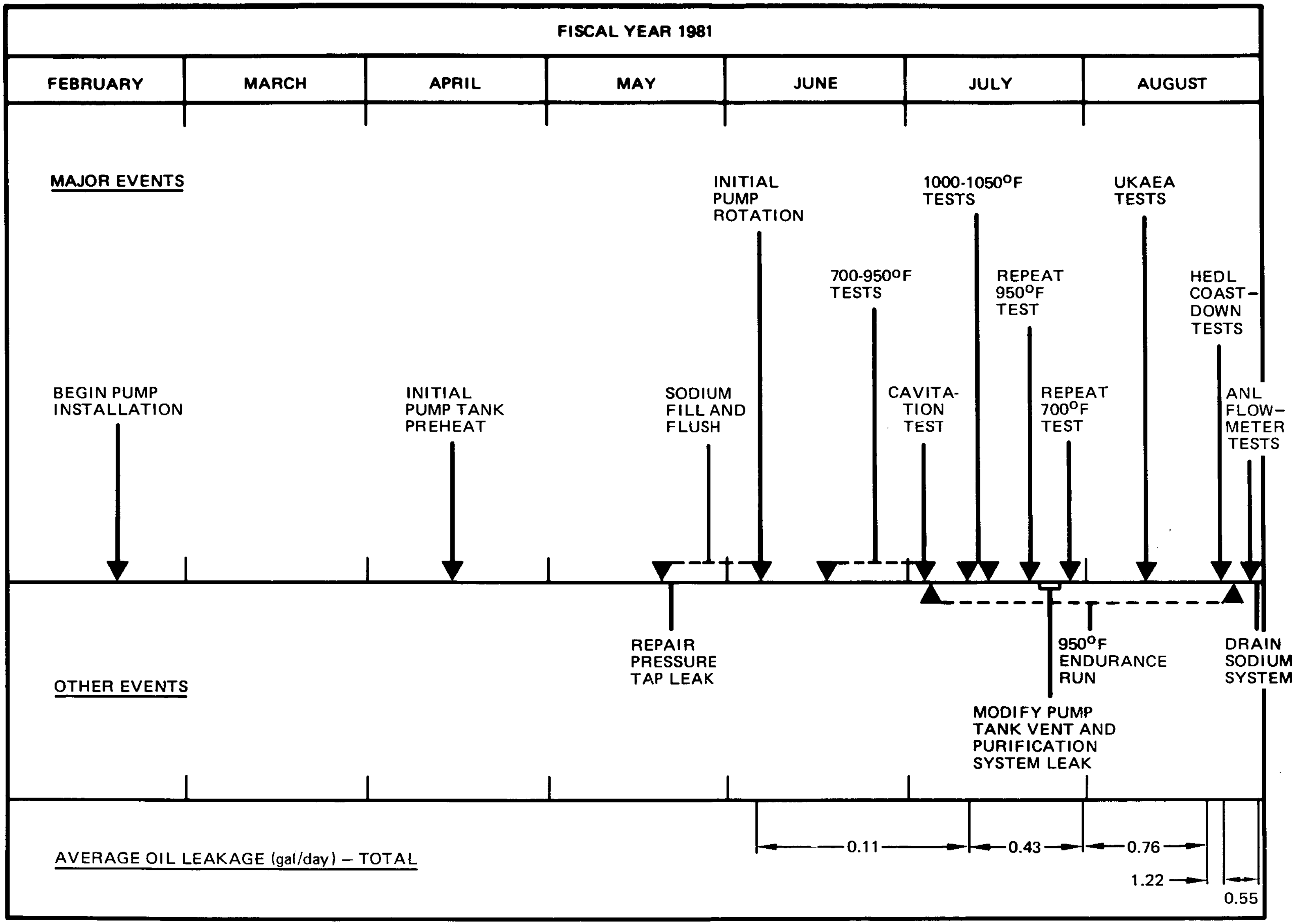

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Figure 31. ISIP-II Test Program Chronology

TABLE 5

ISIP-II TEST MATRIX

SODIUM TEMPERATURE	R4 SPEED SCAN	R5 SPEED SCAN	FLOW SCAN	CAVITATION TEST	ENDURANCE RUN (h)
700°F (371.1°C)	X(2)	X	X		
750°F (398.9°C)	X				
850°F (454.4°C)	X				
950°F (510°C)	X(3)	X	X	X	942.3
1000°F (537.8°C)	X				
1050°F (565.6°C)	X				48.1

B. ADJUSTMENTS TO DATA

Actual pump operating conditions rarely exactly match the targeted operating points. Therefore, test data were adjusted to the targeted test conditions in order to present all test data on the same basis.

Speed scan data points were adjusted to the specified targeted operating speeds of 600, 700, 800, 900, 950, 1000, 1025, 1050, 1075, and 1110 rpm. However, every specified operating speed was not achieved for every test.

Flow scan data and adjusted cavitation test data were adjusted to 1110 rpm. Data points outside of a band width of ±7 rpm of the specified operating speed were not shown on the data plots unless it is specifically noted that all points are plotted.

The following notations are used in the expressions for adjusted parameters:

Notation

N = pump speed (rpm)
Q = flow rate [gpm (m^3/s)]
Head = total head, [ft of sodium (m)]
PWR = total input power to main motor [kW (J)]

Greek Letters

η = efficiency (%)
ρ = density [lb/ft^3 (kg/m^3)]

Subscripts

p = projected value
m = measured value

1. Adjustments to Performance

Flow Adjustment — Flow was adjusted to the specified operating speed as follows:

$$Q_p = Q_m \left(\frac{N_p}{N_m} \right) \quad \text{(IX-1)}$$

Head Adjustments — The adjusted total head shown plotted in the data curves was adjusted to the specified speed as follows:

$$Head_p = Head_m \left(\frac{N_p}{N_m} \right)^2 \quad \text{(IX-2)}$$

Power Adjustments — The measured power to drive the pump is the total main motor input power, which includes liquid rheostat losses. The measured input power, therefore, cannot be projected from the (speed ratio)^3 relationship as is common practice for centrifugal pumps.

An empirical relationship established for FFTF prototype pump testing[10] was used to project measured pump power to the specified speed and temperature as follows:

$$PWR_p = PWR_m \left(\frac{N_p}{N_m}\right)^{1.895} \left(\frac{\rho_p}{\rho_m}\right) \frac{[1 + 9.8(10^{-6})(T_p - 70)]}{[1 + 9.8(10^{-6})(T_m - 70)]} \qquad \text{(IX-3)}$$

Equation IX-3 was shortened for the ISIP-II program as follows:

$$PWR_p = PWR_m \left(\frac{N_p}{N_m}\right)^{1.895} \left(\frac{\rho_p}{\rho_m}\right) \qquad \text{(IX-4)}$$

Temperature adjustments were less than 10^oF (5.6^oC) for all data presented herein; therefore, the temperature adjustment factor of Equation IX-3 became trivial. The density ratio factor was left in Expression IX-4 as a temperature correction.

C. CURVE FITS AND PLOTS

The data curves presented herein were curve fit with a best-fit computer-generated equation. The curve-fit equation generally was in the form of a second-order polynomial, even though the pump affinity laws might indicate that another form was more appropriate. Therefore, caution should be exercised in using the curve-fit equations to extrapolate the data beyond the test values.

The data presented in the speed scan and flow scan plots are steady-state data. Speed scan data were selected for points within ±7 rpm of the specified operating speed. Flow-divided-by-speed (Q/N) points within ∿0.75% of the specified Q/N target value were selected. Transient data are thus eliminated.

A typical Q/N plot of selected data is shown in Figure 32. It should be noted that the selected range of steady-state data for presentation is within 0.77% of the targeted Q/N of 13.063, whereas the RFT allows data within 2.0% to be selected. The data presented are, therefore, more representative of the pump

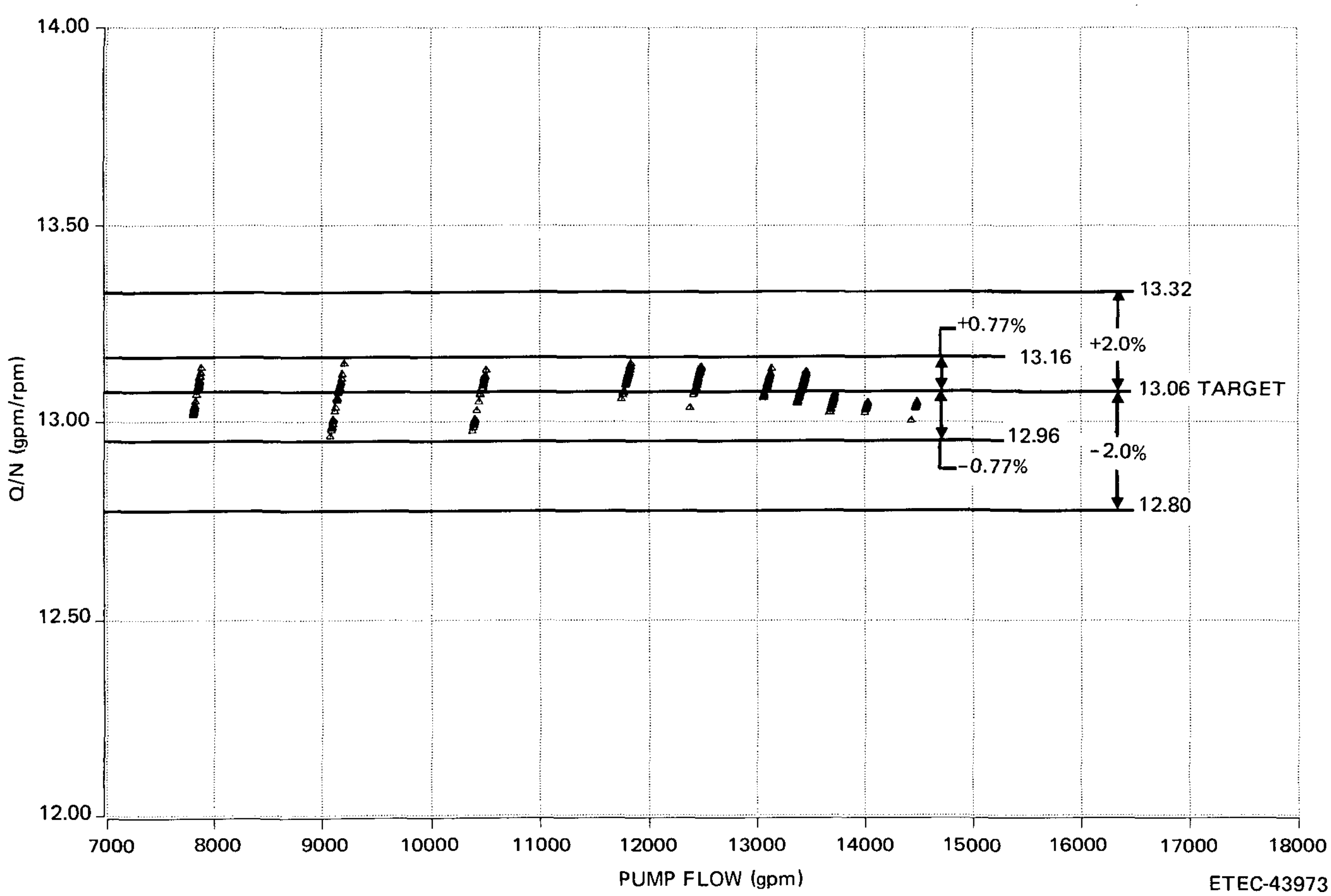


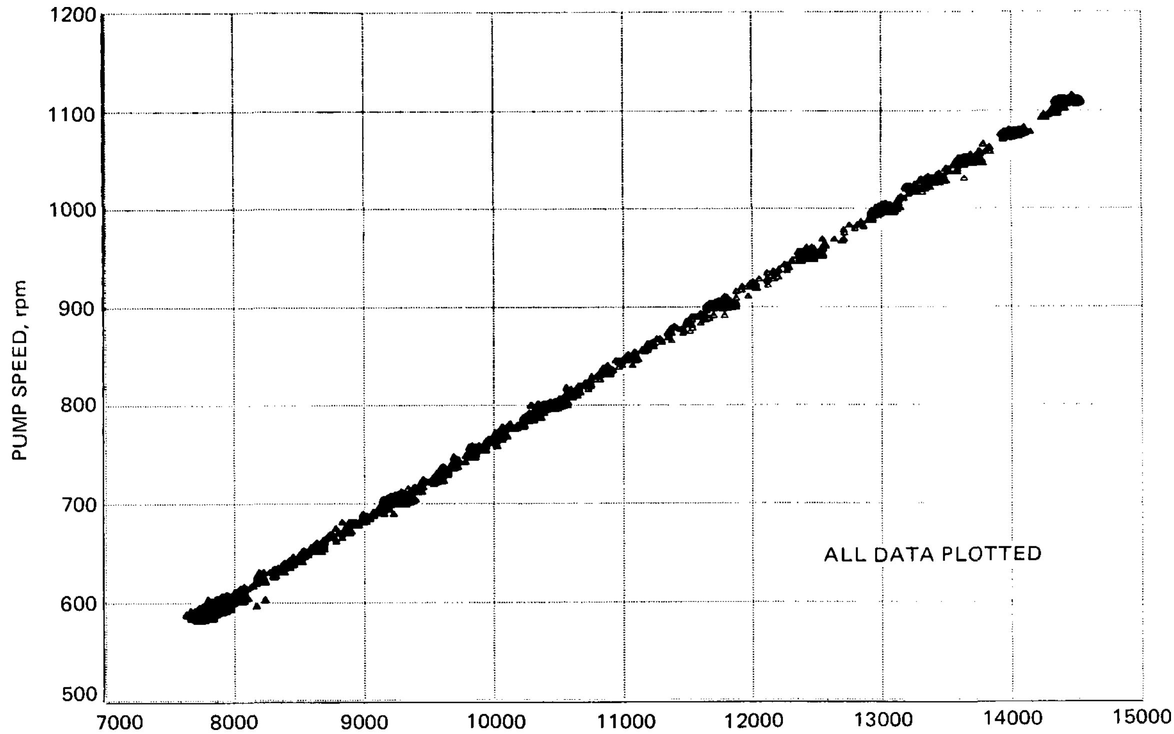
Figure 32. Typical Q/N vs Pump Flow Plot

performance at the specified point. Typical plots of unadjusted data for pump speed, head, power consumption, and computed efficiency vs pump flow rate are shown in Figures 33a through 33d, respectively.

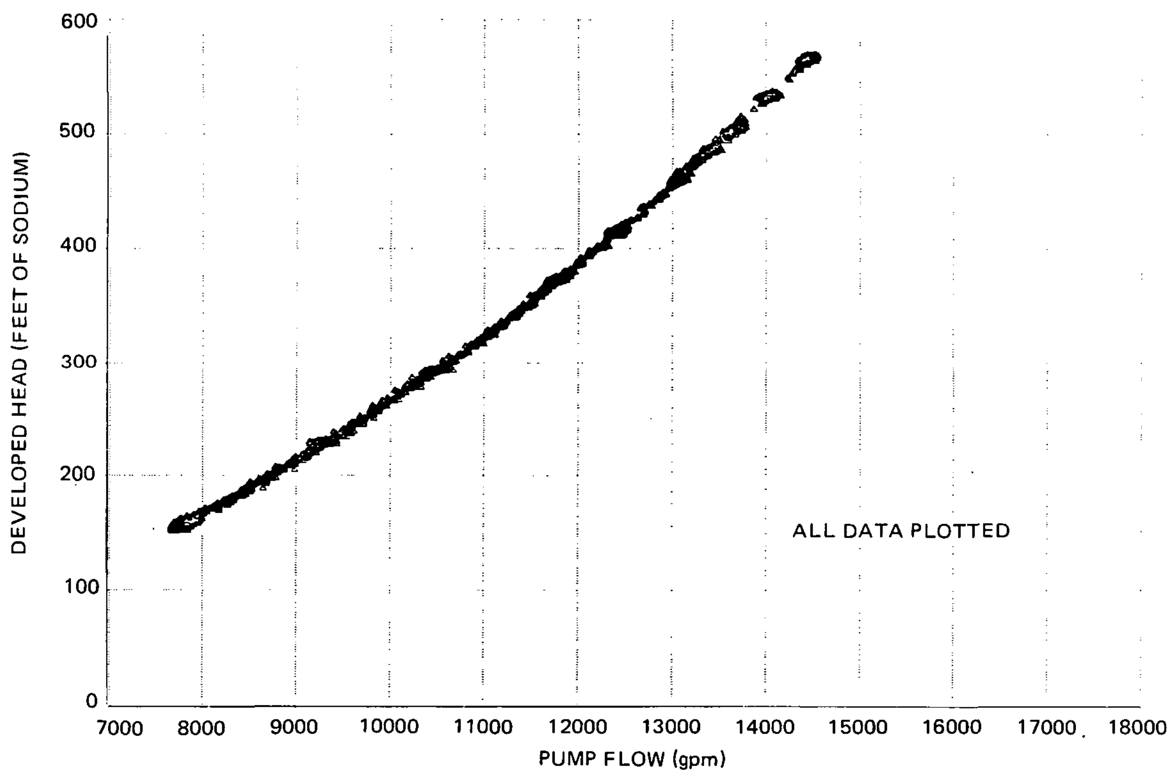
D. PUMP PERFORMANCE

1. Data Analysis

Data Summary — The pump performance tests for flow, head, power consumption, and computed efficiency (adjusted to 1110 rpm) are presented in Tables 6A and 6B. Table 6A also contains the test description, the date and time of the test, the Q/N range plotted, and a reference to the figure numbers where the data plotted for these tests can be found. Note that the pump data presented in Table 6A are in British units, whereas the same data presented in Table 6B are in SI units.



A. TYPICAL UNADJUSTED DATA PLOTS, SPEED



B. TYPICAL UNADJUSTED DATA PLOTS, HEAD

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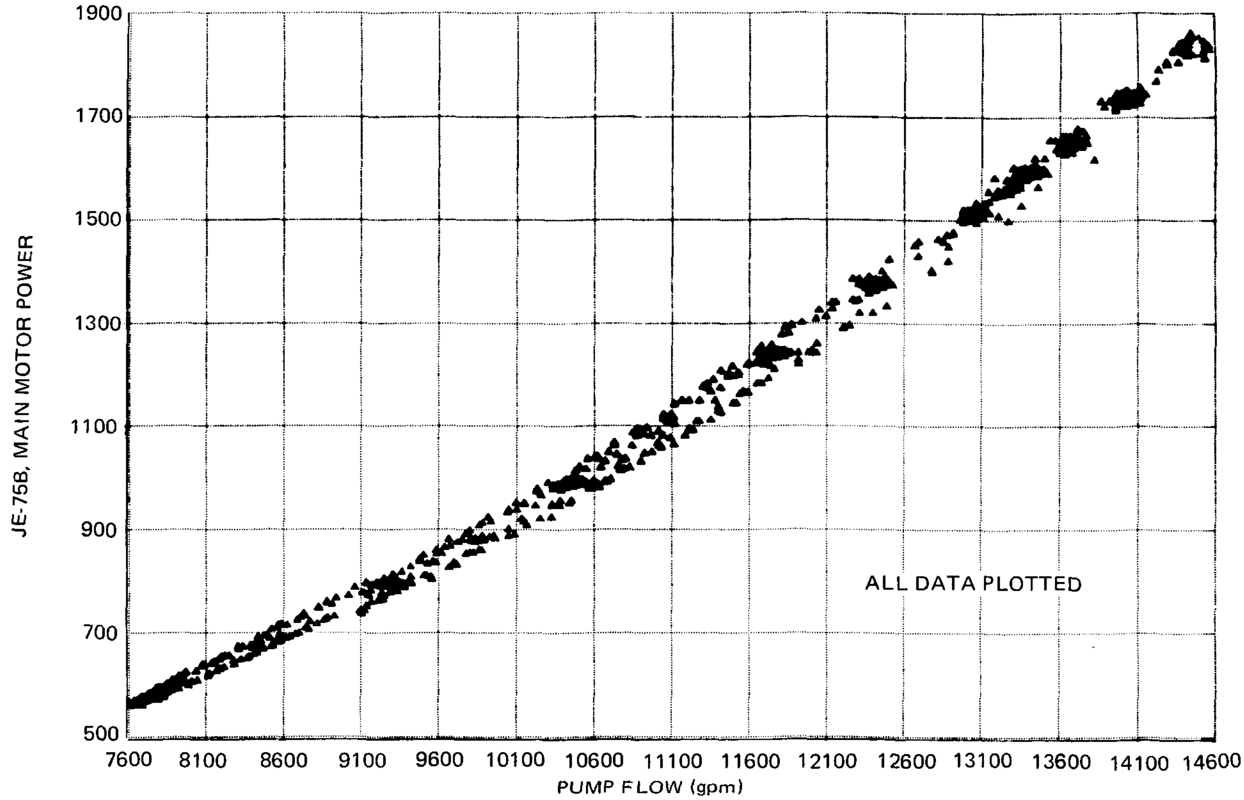
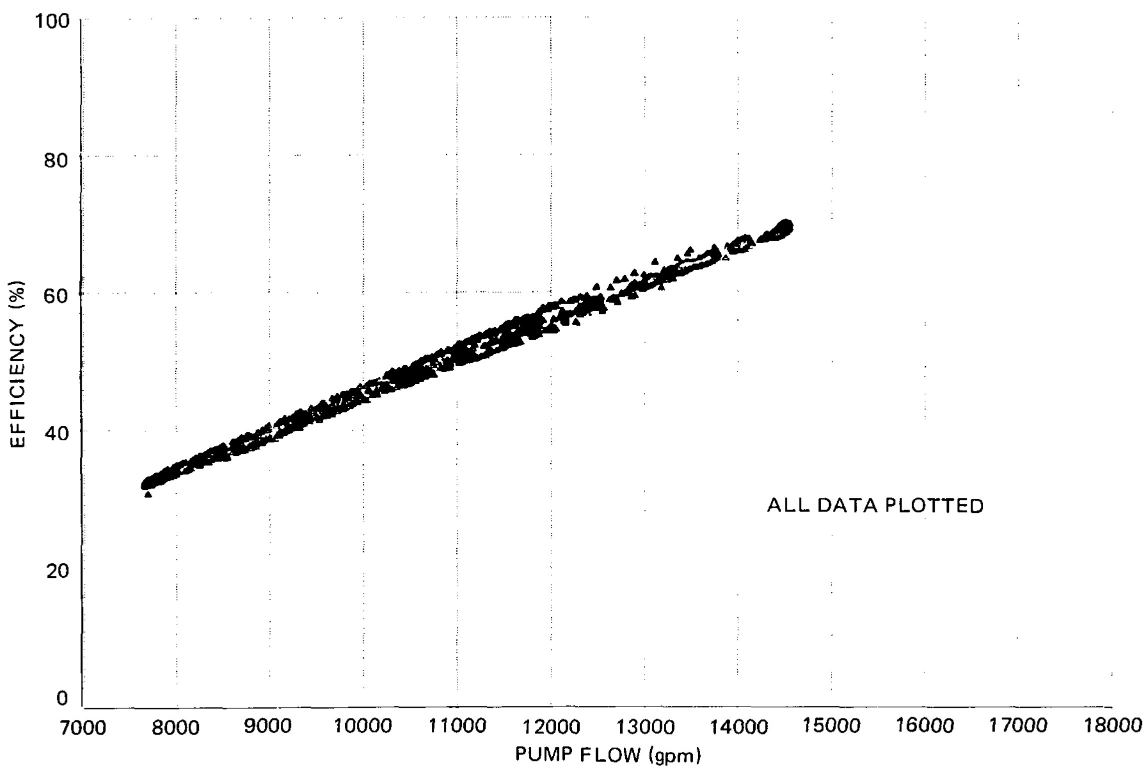
Figure 33. Typical Unadjusted Data Plots
(Sheet 1 of 2)



C. TYPICAL UNADJUSTED DATA PLOT, POWER



D. TYPICAL UNADJUSTED DATA PLOT, EFFICIENCY

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Figure 33. Typical Unadjusted Data Plots (Sheet 2 of 2)

TABLE 6A

ISIP-II ADJUSTED TEST DATA SUMMARY (BRITISH UNITS)

Date of Test	Type of Test[2]	Time of Test	Reference Figures	Q/N Range Plotted	Measured Data Adjusted to 1110 rpm: Flow (gpm)	Measured Data Adjusted to 1110 rpm: Head (feet)	Measured Data Adjusted to 1110 rpm: Power (kW)	Measured Data Adjusted to 1110 rpm: Efficiency (%)	Data Adjusted to Target Flow[1]: Head (feet)	Data Adjusted to Target Flow[1]: Power (kW)	@ 1110 rpm Operating Specific Speed	@ 14,500 gpm Operating Specific Speed
July 27-28, 1981	700°F R4 SS	2300 start 0150 end	34, 36, 37	12.96-13.16	14,485	564.1	1,920	69.1	565.3	1,924	1,154.2	1,152.9
June 21, 1981	750°F R4 SS	1920-2320	40	12.7-13.0	14,100	553.5	1,850	68.0	---[3]	---[3]	---[3]	---[3]
June 24, 1981	850°F R4 SS	0000-0400	41	12.96-13.16	14,365	556.2	1,883	67.3	566.7	1,917	1,161.6	1,150.8
July 15-16, 1981	950°F R4 SS	2025 start 0040 end	35, 42	12.96-13.16	14,500	562.9	1,838	69.4	562.9	1,838	1,156.6	1,156.6
July 8, 1981	1000°F R4 SS	0200-0635	32, 45	12.96-13.16	14,475	568.8	1,845	68.8	570.8	1,851	1,146.6	1,144.6
July 9-10, 1981	1050°F R4 SS	2150 start 0215 end	36, 46	12.96-13.16	14,495	565.1	1,828	68.9	565.5	1,829	1,153.0	1,152.6
June 19-20, 1981	700°F R5 SS	0110-0320, 0655-1120	34, 38	15.70-16.37	17,475	509.1	2,107	68.5	540.1	2,229	1,369.1	1,329.2
June 29, 1981	950°F R5 SS	0230-0745	35, 43	15.9-16.16	17,745	512.3	2,070	68.6	527.1	2,127	1,373.1	1,353.8
June 20, 1981	700°F 7-PT FS	1830-2240	34, 39	12.96-13.16	14,500[3]	558.0	1,904	68.8	558.0	1,904	1,164.2	1,164.2
June 30, 1981	950°F 7-PT FS	0140-0620	35,44	12.96-13.16	14,500[3]	561.1	1,849	68.7	561.1	1,849	1,159.4	1,159.4
July 2, 1981	950°F 4-PT FS	0320-0535	48	13.08-13.28	14,500[3]	561.6	1,850	68.8	561.6	1,850	1,158.6	1,158.6

$ON_{S_{Avg}}$ R4 = 1,156.8 @ 1,110 rpm $\quad$ $ON_{S_{Avg}}$ R5 = 1,371.1 @ 1,110 rpm

$ON_{S_{Avg}}$ R4 = 1,155.0 @ 14,500 gpm $\quad$ $ON_{S_{Avg}}$ R5 = 1,341.5 @ 14,500 gpm

Notes:

1. Data adjusted to targeted flows:
   R4 = 14,500 gpm at 1,110 rpm
   R5 = 18,000 gpm at 1,110 rpm
2. SS = speed scan, FS = flow scan
3. Data out of Q/N range; not extrapolated

TABLE 6B

ISIP-II ADJUSTED TEST DATA SUMMARY (SI UNITS)

Test Date	Type of Test[2]	Measured Data Adjusted to 1110 rpm			Data Adjusted to Target Flow[1]	
		Flow (m^3/s)	Head (m)	Power (kW)	Head (m)	Power (kW)
July 27-28, 1981	371.1°C R4 SS	0.9139	171.9	1,920	172.3	1,924
June 21, 1981	398.9°C R4 SS	0.8896	168.7	1,850	---[3]	---[3]
June 24, 1981	454.4°C R4 SS	0.9063	169.5	1,883	172.7	1,917
July 15-16, 1981	510°C R4 SS	0.9148	171.6	1,838	171.6	1,838
July 8, 1981	537.8°C R4 SS	0.9132	173.4	1,845	174.0	1,851
July 9-10, 1981	565.6°C R4 SS	0.9145	172.2	1,828	172.4	1,829
June 19-20, 1981	371.1°C R5 SS	1.1025	155.2	2,107	164.6	2,229
June 29, 1981	510°C R5 SS	1.1195	156.1	2,070	160.7	2,127
June 20, 1981	371.1°C 7-PT FS	0.9148	170.0	1,904	170.1	1,904
June 30, 1981	510°C 7-PT FS	0.9148	171.0	1,849	171.0	1,849
July 2, 1981	510°C 4-PT FS	0.9148	171.2	1,850	171.2	1,850

Notes:

1. Data adjusted to targeted flows:
   R4 = 0.91481 m^3/s
   R5 = 1.13562 m^3/s
2. SS = speed scan, FS = flow scan
3. Data out of Q/N range, not extrapolated

Post-test calibration of the pump discharge pressure transducer (PT-105) was found to be 2.25% higher than the pretest calibration. The developed head is usually computed from the pump discharge pressure. In this instance, the developed head was also computed from another pressure transducer (PT-106) farther downstream of the pump discharge pressure transducer as a check. The developed head calculated from the downstream transducer (PT-106) provided corroboration that the posttest calibration on the pump discharge pressure transducer (PT-105) should be used for performance calculations.

Operating Condition History — A summary of the pump operating history from the time of initial powered pump rotation until the final motor shutdown is presented in Table 7.

TABLE 7

ISIP-II OPERATING CONDITION HISTORY

Speed (SE-47) (rpm)	Temperature (^{o}F) Less Than 575	575 to 775	775 to 975	Over 975	Total Hours
Less than 400	140.4	89.7	57.4	7.7	295.2
400 to 800	39.0	193.0	364.2	35.4	631.6
800 to 1000	0.6	7.9	20.3	3.2	32.0
Over 1000	0.4	15.0	1011.0	52.1	1078.5
Total					2037.3

Interval from 6/5/81 at 15:42 to 8/29/81 at 13:58	
Time exposure (hours):	
Pony motor only	109.4
Main motor	1759.8
Motor stopped during this period	68.1
950^{o}F endurance run (NPSH = 29 ft)	941.0
Cavitation test (NPSH < 29 ft)	1.3
1050^{o}F endurance run	48.1

The pump was operated under power for 1869.2 h, of which 1759.8 h were at main motor speed. A total of 1011 h of pump operation was accumulated at a pump speed above 1000 rpm with the sodium temperature ranging from 775°F (412.8°C) to 975°F (523.9°C). A total of 941 h at the 950°F (510°C) reduced-NPSH endurance run condition was accumulated. This was the longest run duration practical because another pump test program was scheduled to be run in SPTF.

2. Performance Parameters

Total Head — The head or total head, as used herein, is defined as the total dynamic head, expressed as the height of a column of sodium corresponding to the pressure increase produced by the pump. Included in the value for the head is the difference in velocity heads at points in the inlet and discharge line where the pressure is measured.

The discharge pressure is measured at a point downstream of the pump in the discharge ducting. The velocity head is calculated for the piping cross-sectional area at that point. The fluid friction loss from the pump discharge to the point where the discharge pressure is measured is calculated and added to the calculated discharge head.

The head at the inlet is determined from the height of the column of sodium above the reference point (inducer inlet) plus the cover gas pressure equivalent head in the pump tank. The inlet velocity head is computed at the inducer inlet cross-sectional area and added to the inlet head computed above.

This method of computing the inlet head was used during the latter part of the FFTF pump test program. It is believed to be a more accurate and stable technique of determining the inlet head than computing the inlet head from the pressure reading in the inlet ducting.

Head-vs-Flow Pump Characteristics — The pump demonstrated good head-vs-flow mapping repeatability at all temperatures. Mapping at R4 and R5 speed scans and flow scans was performed at sodium temperatures of 700°F (371.1°C) and 950°F

(510^{o}C). The head-flow and power-flow maps for 700^{o}F (371.1^{o}C) are presented in Figures 34a and 34b, respectively. The head- and power-vs-flow maps at 950^{o}F (510^{o}C) are presented in Figures 35a and 35b, respectively.

The head- and power-vs-flow characteristics at the extremes of operating temperatures, 700^{o}F (371.1^{o}C) and 1050^{o}F (565.6^{o}C) for the R4 system resistance condition is shown in Figures 36a and 36b. It can be seen from Figure 36a that the head-vs-flow characteristics are essentially the same. Minor deviation is due to normal random data scatter and to the diurnal effect on the speed indicator tachometer generator. The diurnal effect is discussed later in this section.

Total head data for each test series were extracted from Tables 6A and 6B and is presented in Table 8 for clarity. The data presented in Table 8 are adjusted to 1110 rpm.

The average head at R4 resistance is 562.2 ft (171.4 m). The maximum deviation is +1.0%, -0.7%. Data for the 750^{o}F (398.9^{o}C) R4 speed scan are not included because they are outside the range of all other data presented.

The average head at R5 resistance is 510.7 ft (155.7 m). It should be noted that there are only two data points for the R5 resistance at 1110 rpm.

Measured Power – The measured power as used herein refers to the total input power to the main motor, including losses due to the liquid rheostat. There was no provision to isolate the main motor power consumption from the rheostat losses. The similarity relations regarding power, therefore, do not strictly apply. A special correlation factor was used to extrapolate power data for different speed conditions.

Power-vs-Flow Characteristics – The power-flow maps for the 700^{o}F (371.1^{o}C) and 950^{o}F (510^{o}C) temperature runs were shown in Figures 34b and 35b, respectively. R4 and R5 speed scans and a flow scan (at constant speed of 1110 rpm) comprise each of the maps.

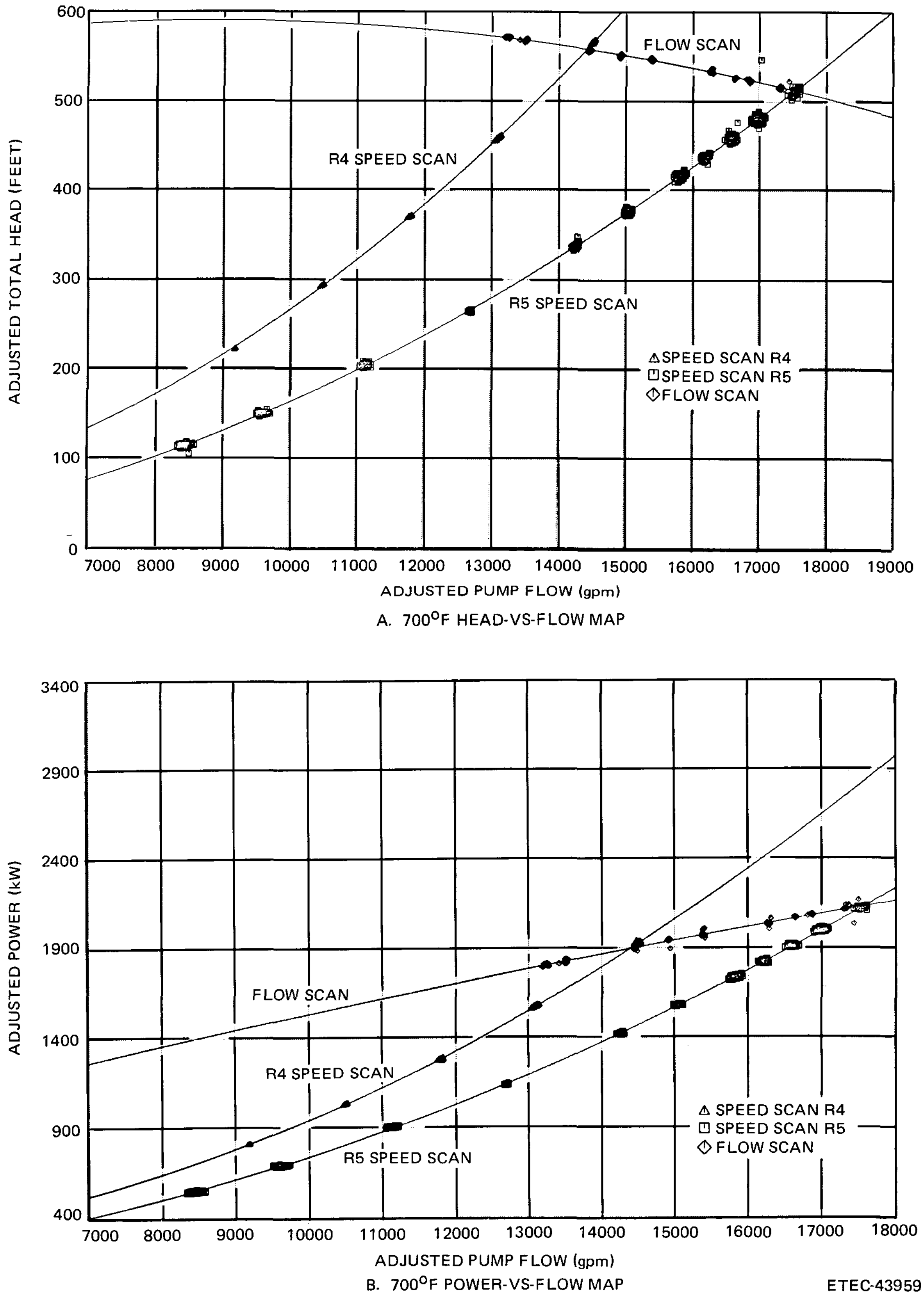
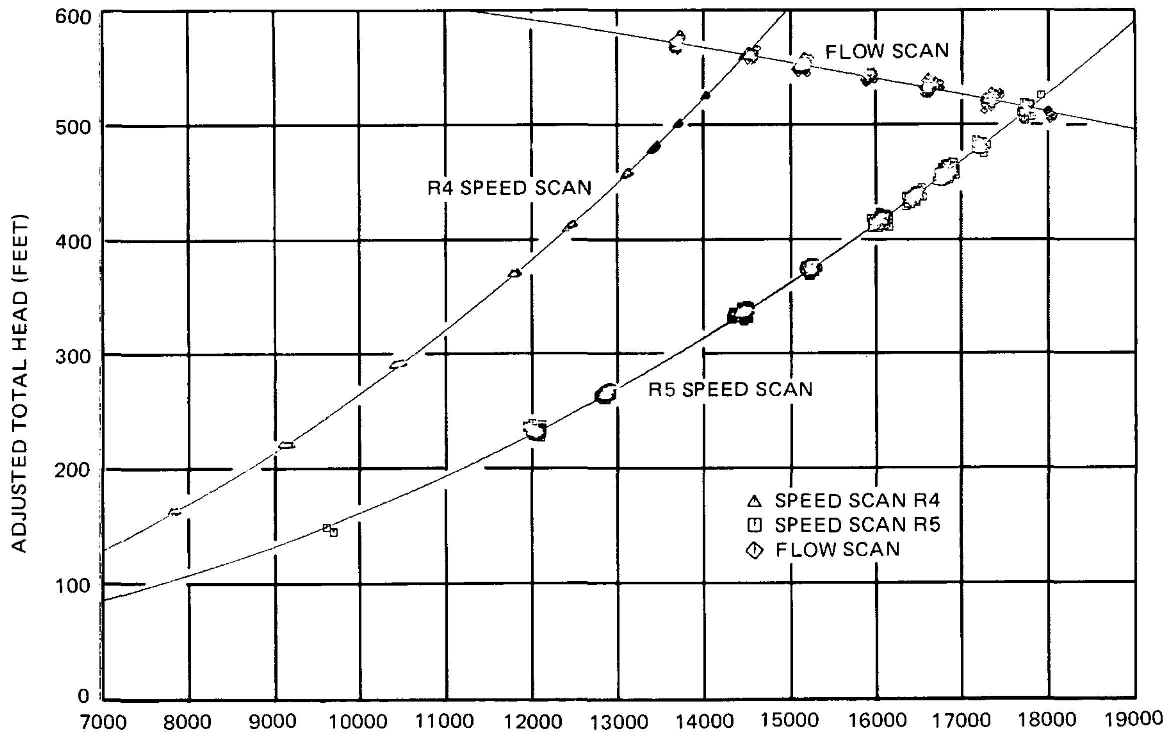
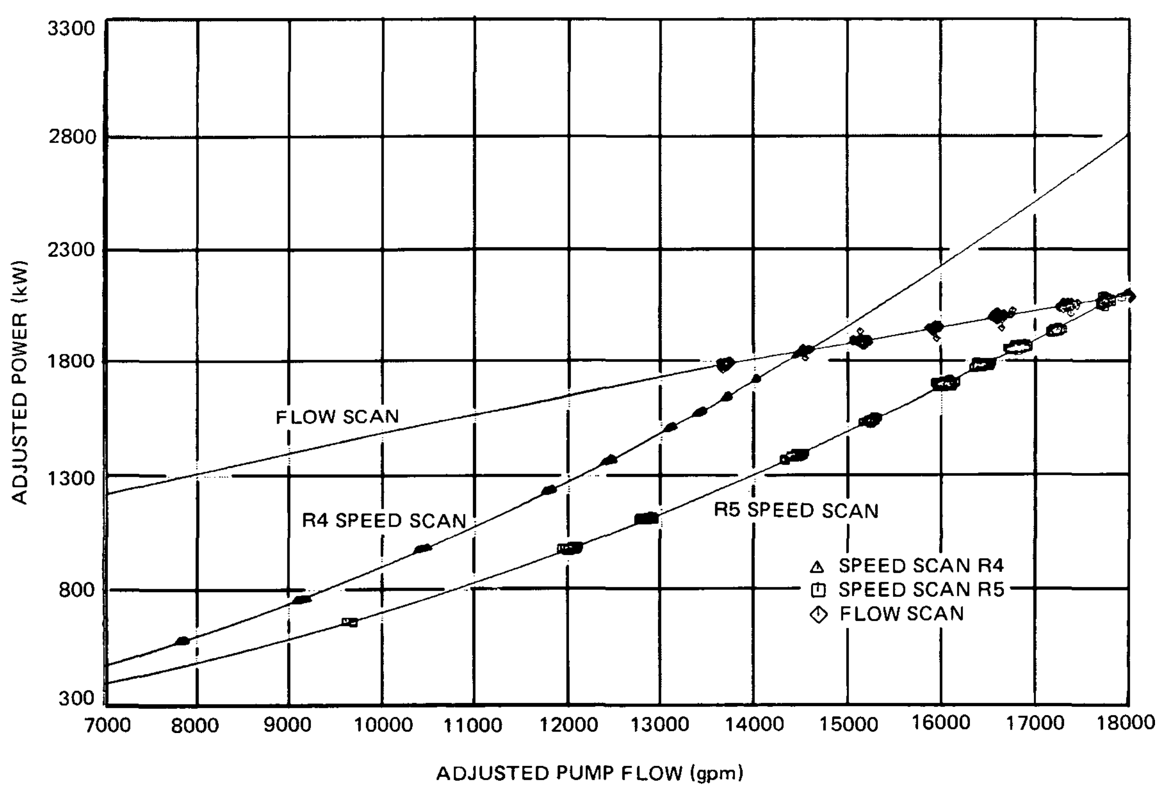


Figure 34. 700°F Performance Map



A. 950°F HEAD-VS-FLOW MAP



B. 950°F POWER-VS-FLOW MAP

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Figure 35. 950°F Performance Map

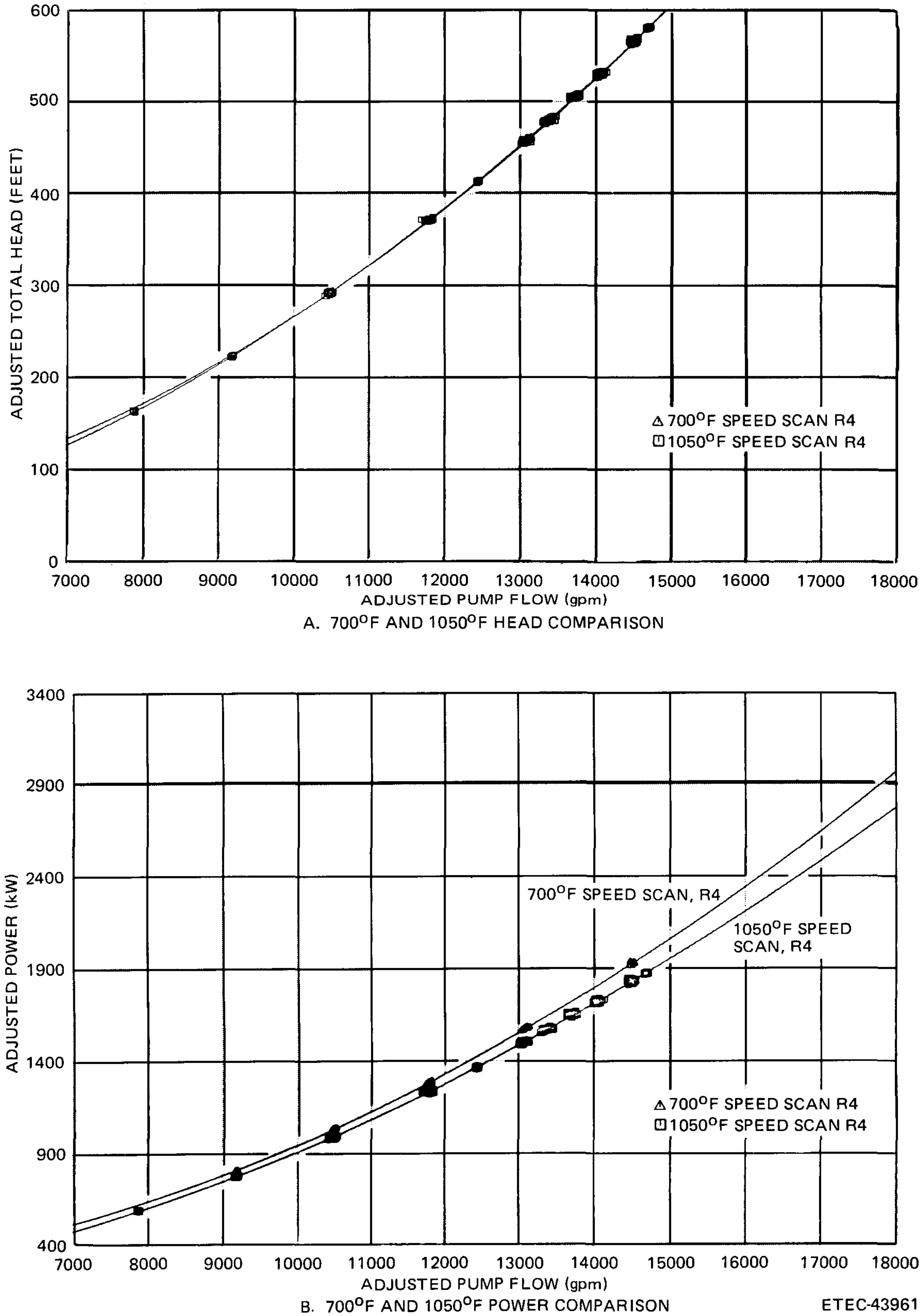


Figure 36. 700°F and 1050°F Performance Comparison Plots

TABLE 8

ISIP-II TOTAL HEAD AT 1110 rpm

Test Date	Type Test, R4[1]	Head[2] ft	Head[2] m
July 27-28, 1981	700°F (371.1°C) SS	564.1	171.9
June 24, 1981	850°F (454.4°C) SS	556.2	169.5
July 15-16, 1981	950°F (510°C) SS	562.9	171.6
July 8, 1981	1000°F (537.8°C) SS	568.8	173.4 (maximum)
July 9-10, 1981	1050°F (565.6°C) SS	565.1	172.2
June 20, 1981	700°F (371.1°C) 7-PT FS	558.0	170.1 (minimum)
June 30, 1981	950°F (510°C) 7-PT FS	561.1	171.0
July 2, 1981	950°F (510°C) 4-PT FS	561.6	171.2
		562.2	171.4 average
		+1.2, -0.7 maximum deviation (%)	
		3.99 ft (1.22 m) standard deviation	

Test Date	Type Test, R5[1]	Head ft	Head m
June 19-20, 1981	700°F (371.1°C) SS	509.1	155.2
June 29, 1981	950°F (510°C) SS	512.3	156.1
		510.7	155.7 average

Notes:

1. SS = speed scan, FS = flow scan
2. NPSH = 60 ft (18.3 m)

A comparison of the power-flow characteristics for the test program extremes of 700°F (371.1°C) and 1050°F (565.6°C) temperature conditions at R4 system resistance was shown in Figure 36b. The higher power requirements at the 700°F (371.1°C) temperature is to be expected because of the higher density sodium being pumped at the lower temperature.

The measured power requirement was 1925.2 kW at a sodium temperature of 700°F (371.1°C) adjusted to 1110 rpm. The projected power at 1050°F (565.6°C) at 1110 rpm using Equation IX-4 is 1827.5 kW. This falls within 0.1% of the actual measured power of 1829.8 kW at 1050°F (565.6°C) adjusted to 1110 rpm for the R4 system resistance.

The power-vs-flow curve at R4 resistance for 950°F is shown in Figure 35b. The projected power requirement at 950°F and 1110 rpm using Equation IX-4 is 1855.5 kW. The projected value is within 1.2% of the actual measured power of 1833.4 kW. This discrepancy is probably due to the diurnal effect on the speed indicator tachometer generator output, as explained later in this section.

The power-vs-flow curves for the 700°F (371.1°C) and the 950°F (510°C) R5 resistance tests are shown in Figures 34b and 35b, respectively. The power required at 1110 rpm for the 700°F (371.1°C) R5 test was 2120 kW. The required power at 950°C (510°C), 1110 rpm, projected from Equation IX-4 is 2043.4 kW. The projected value at 950°F (510°C) was within 1.4% of the actual measured power of 2071.6 kW.

Pump Efficiency — Pump efficiency was calculated from the expression:

$$\eta = (0.01883)\ \frac{(\text{Head})(Q)(\text{sp g})}{(\text{PWR})} \qquad \text{(IX-5)}$$

The average efficiency for the R4 resistance data (adjusted to 1110 rpm) is 68.6%, with the maximum deviation ∿1.0%.

The efficiency quoted is meaningful only for the ISIP-II pump-motor combination (including the liquid rheostat).

E. TEST SERIES

The test objectives of the test series were to:

1) Characterize the pump head, flow, power, and speed relationships.
2) Establish the critical NPSH at design speed and flow rate.
3) Requalify the pump shaft for use in FFTF by operation at 1050°F (565.6°C) for a speed scan and a 48-h duration at steady state at 1110 rpm.
4) Operate the pump at 155% NPSH margin, 950°F (565.6°C), and 1110 rpm for maximum practical duration.

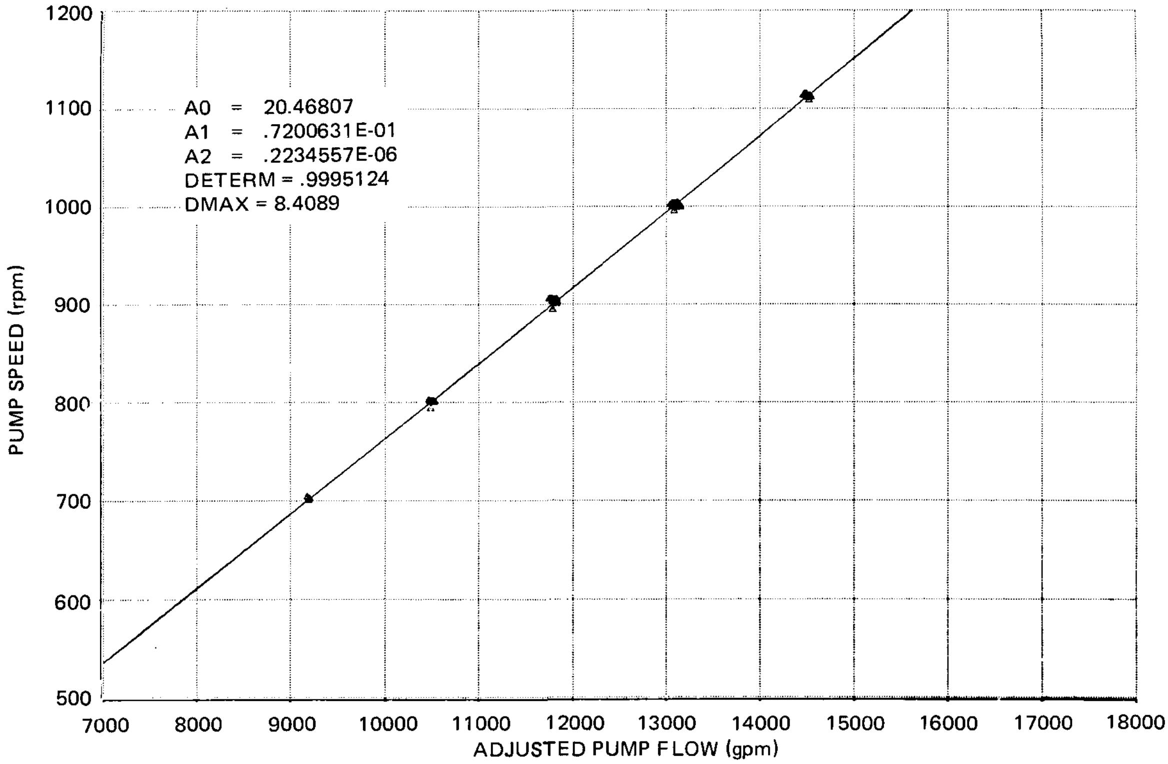
All of these test program objectives were achieved. There were no incidents during the test program that caused damage to the test article or jeopardized personnel safety.

Descriptions of the test performed are presented below.

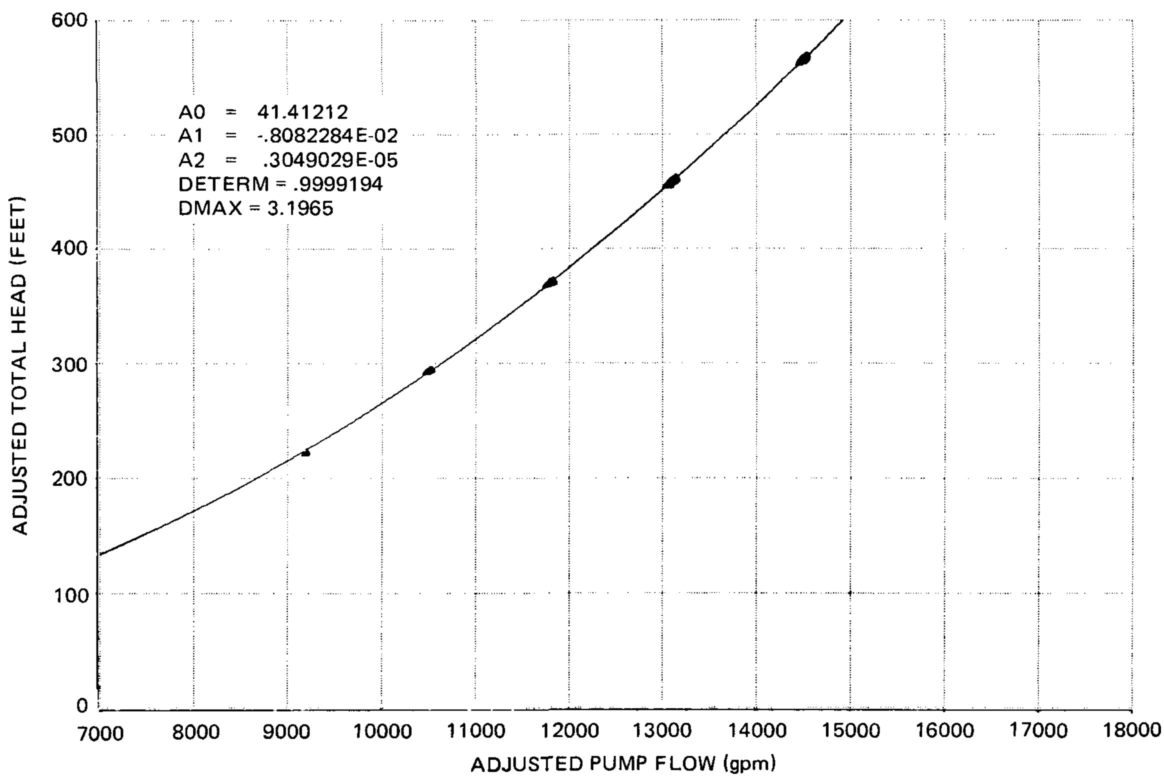
1. 700°F R4 and R5 Speed Scans and Flow Scan

The first R4 speed scan attempted at 700°F (371.1°C) was interrupted several times due to pump trips and instrumentation and facility problems for various reasons. None of the trips or interruptions was due to faulty pump operation. The 700°F (371.1°C) R4 speed scan was repeated after several of the aforementioned problems were resolved.

The data for the second 700°F (371.1°C) R4 speed scan are presented herein. Pump speed, head, power consumption, and calculated efficiency as functions of pump flow are presented as Figures 37a through 37d, respectively, for the 700°F (371.1°C) R4 speed scan and as Figures 38a through 38d for the R5 speed scan.



A. 700°F R4 SPEED SCAN, SPEED



B. 700°F R4 SPEED SCAN, HEAD

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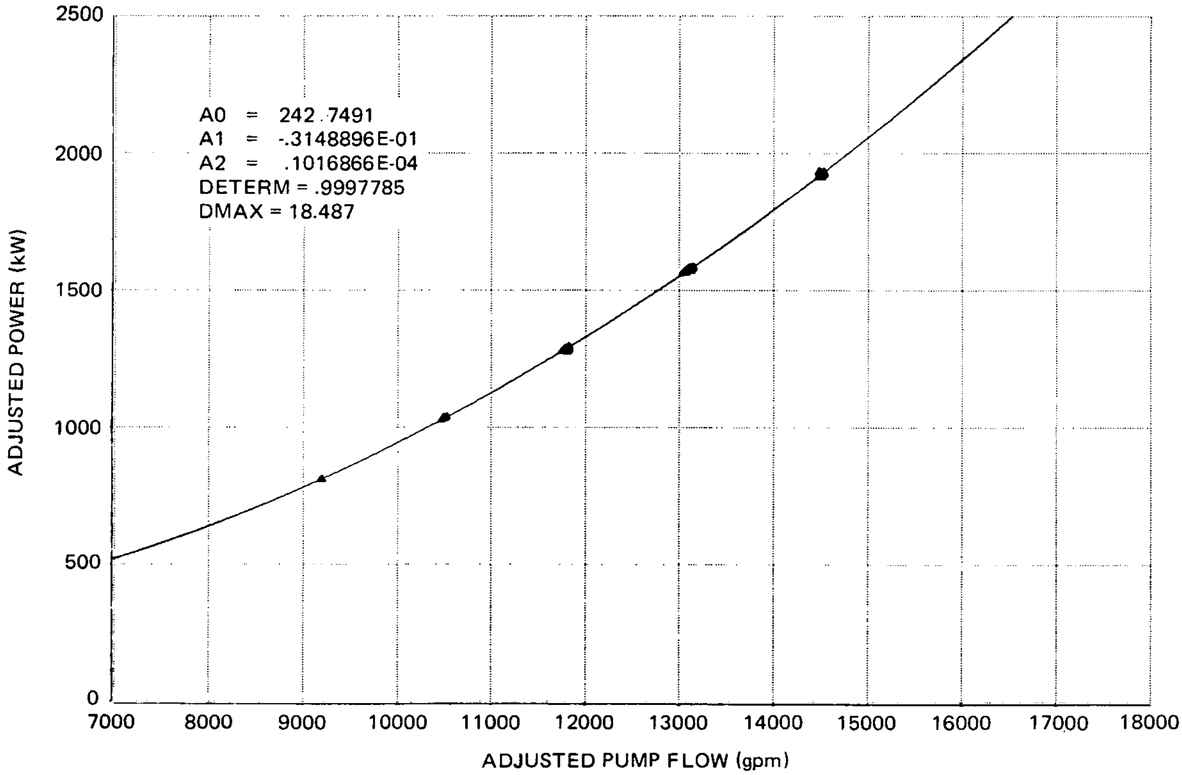
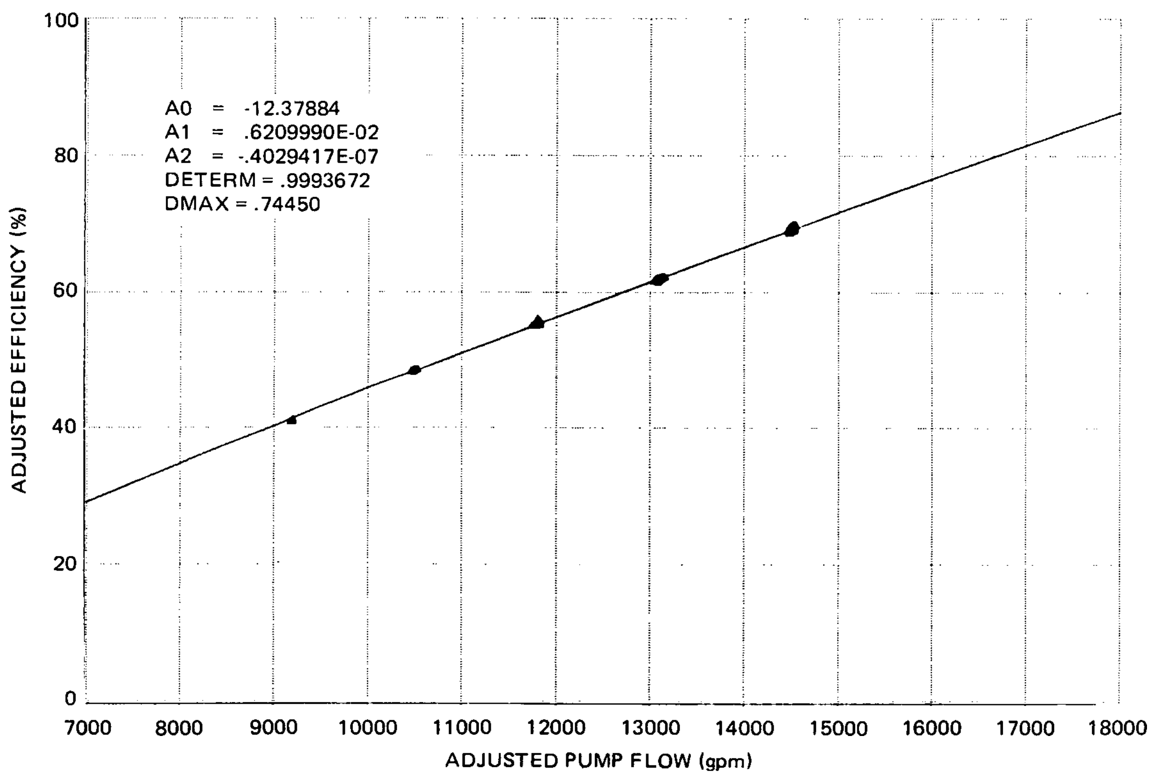
Figure 37. 700°F R4 Speed Scan Data Plots (Sheet 1 of 2)



C. 700°F R4 SPEED SCAN, POWER



D. 700°F R4 SPEED SCAN, EFFICIENCY

ETEC-43977

Figure 37. 700°F R4 Speed Scan Data Plots (Sheet 2 of 2)

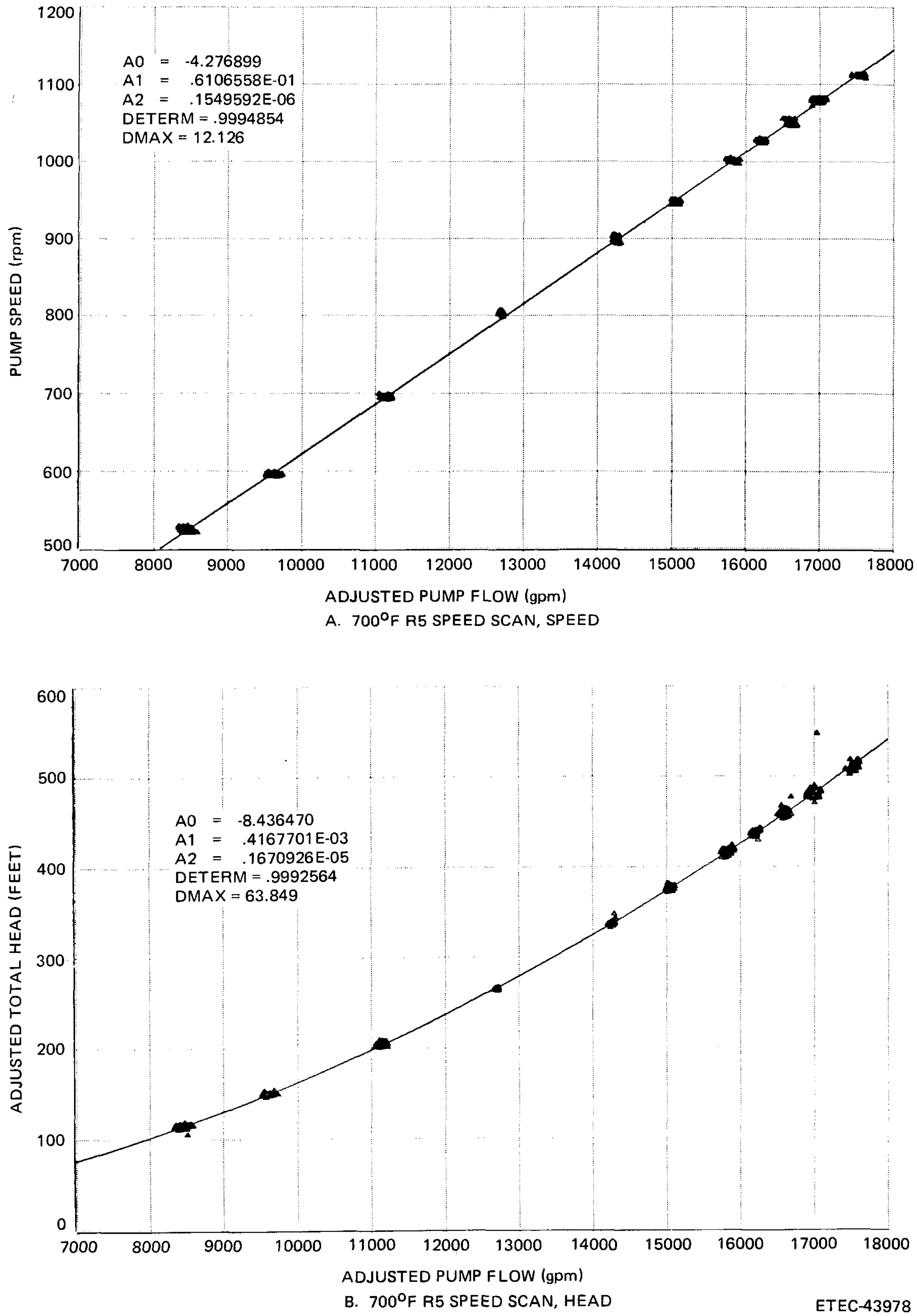
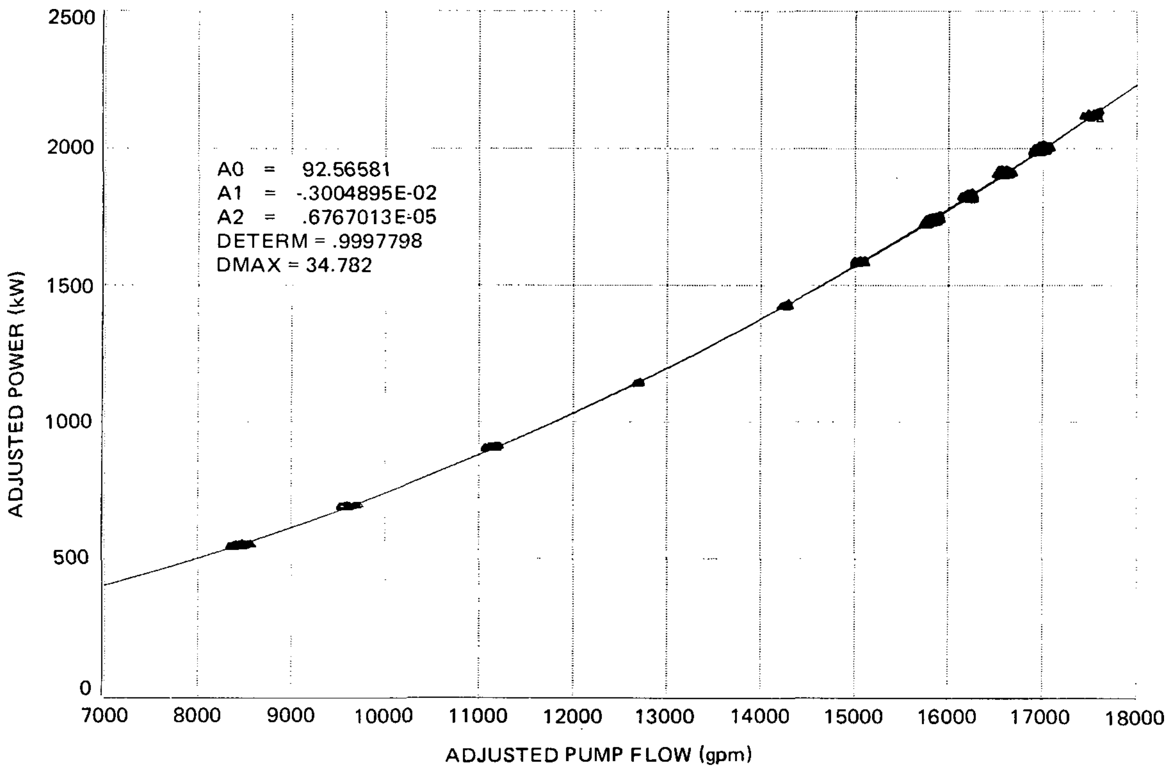
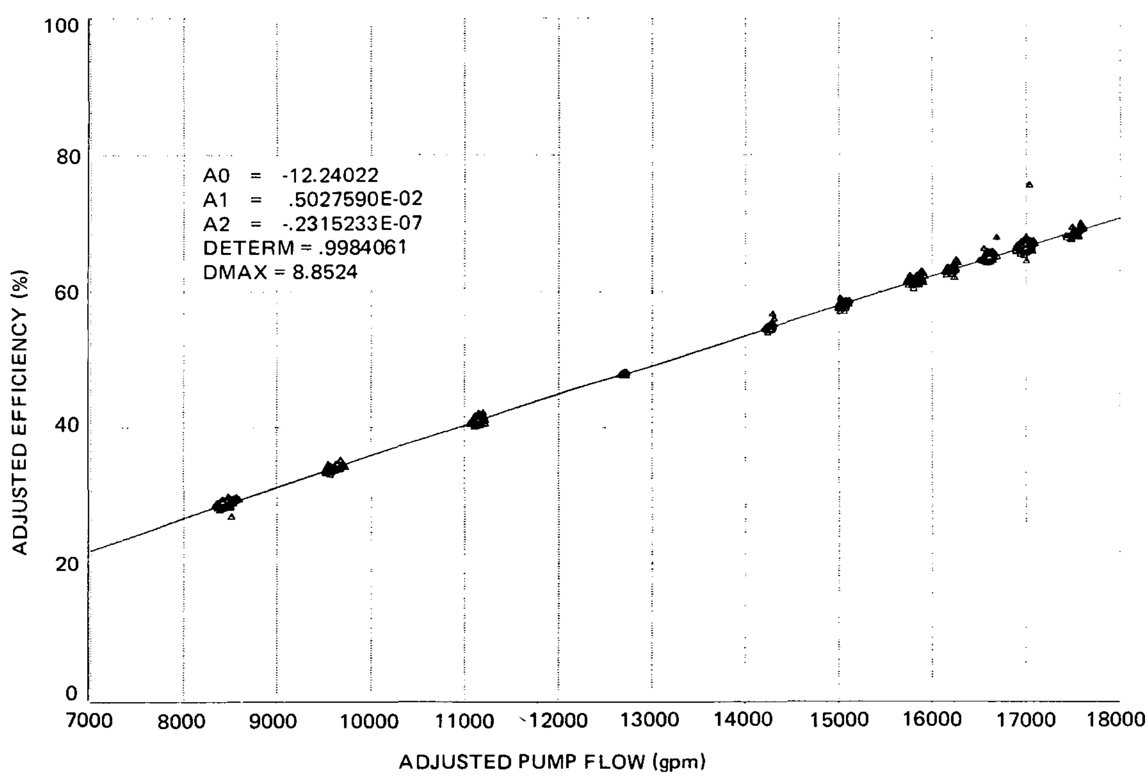


Figure 38. 700°F R5 Speed Scan Data Plots
(Sheet 1 of 2)



C. 700°F R5 SPEED SCAN, POWER



D. 700°F R5 SPEED SCAN, EFFICIENCY

ETEC-43979

Figure 38. 700°F R5 Speed Scan Data Plots
(Sheet 2 of 2)

A flow scan at 700°F (371.1°C) and 1110 rpm was performed over the range of flows from 13,200 gpm to ∿17,400 gpm. The total developed head, power consumption, and efficiency as functions of pump flow are presented as Figures 39a through 39c.

The R4 and R5 speed scans and the flow scan data at 700°F are also presented in Figures 34a and 34b as the pump head and power map curves, respectively.

2. 750°F R4 and R5 Speed Scan

All instrumentation problems had not been recognized when the 750°F (398.9°C) speed scan was conducted. It was later recognized that the method of computing flow rate would produce inaccurate results at certain sodium temperatures. The corrected computed Q/N (gal/rev) value for the 750°F (398.9°C) speed scan was, therefore, somewhat lower than the average Q/N for the remaining reported tests. The Q/N range was 12.7 to 13.0 gal/rev for the 750°F speed scan vs ∿12.96 to 13.16 gal/rev for the remaining reported R4 speed scans.

The data plots of pump speed, head, power consumption, and computed efficiency vs pump flow are presented in Figures 40a through 40d, respectively.

3. 850°F R4 Speed Scan

The data plots of pump speed, head, power consumption, and computed efficiency as functions of pump flow are presented in Figures 41a through 41d, respectively, for the 850°F (454.4°C).

4. 950°F R4 and R5 Speed Scans and Flow Scan

Three R4 speed scans at 950°F (510°C) were performed. Several interruptions occurred while the first two speed scans were being performed. The third R4 speed scan was performed after instrumentation problems were resolved. Data for only the third R4 speed scan are presented here. An R5 speed scan at 950°F (510°C) was also performed. Data plots for pump speed, head, power consumption,

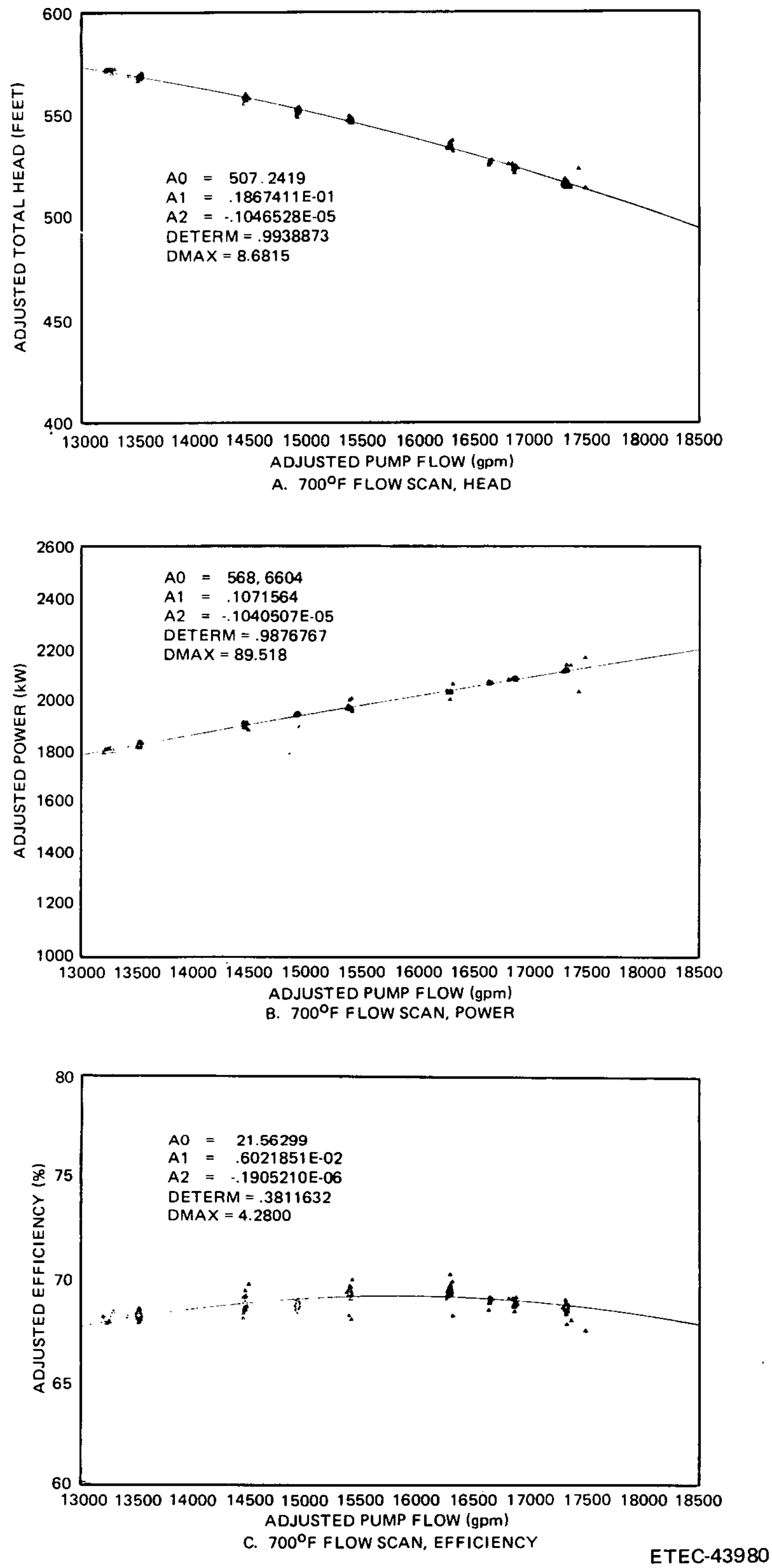


Figure 39. 700°F Seven-Point Flow Scan Data Plots

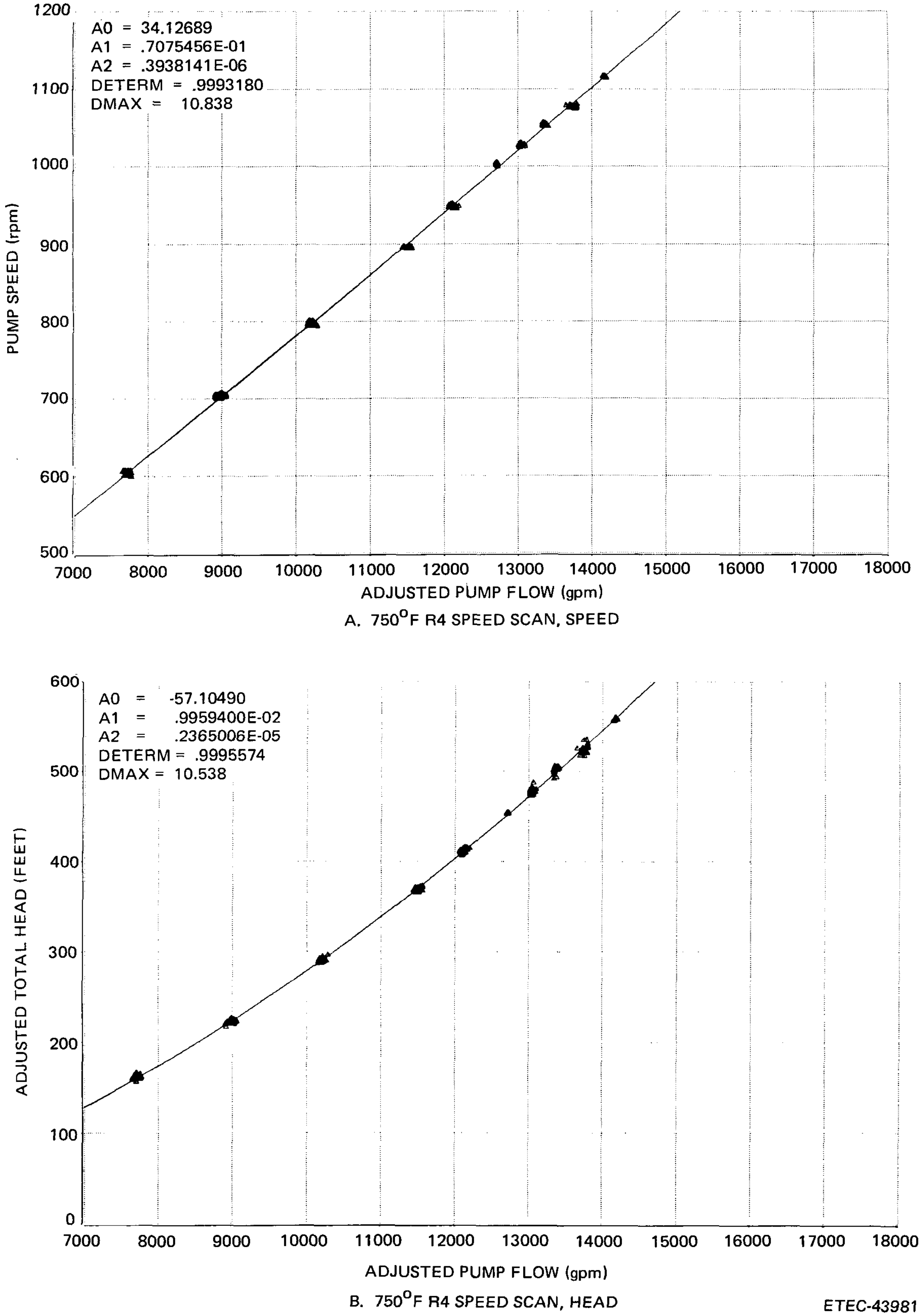
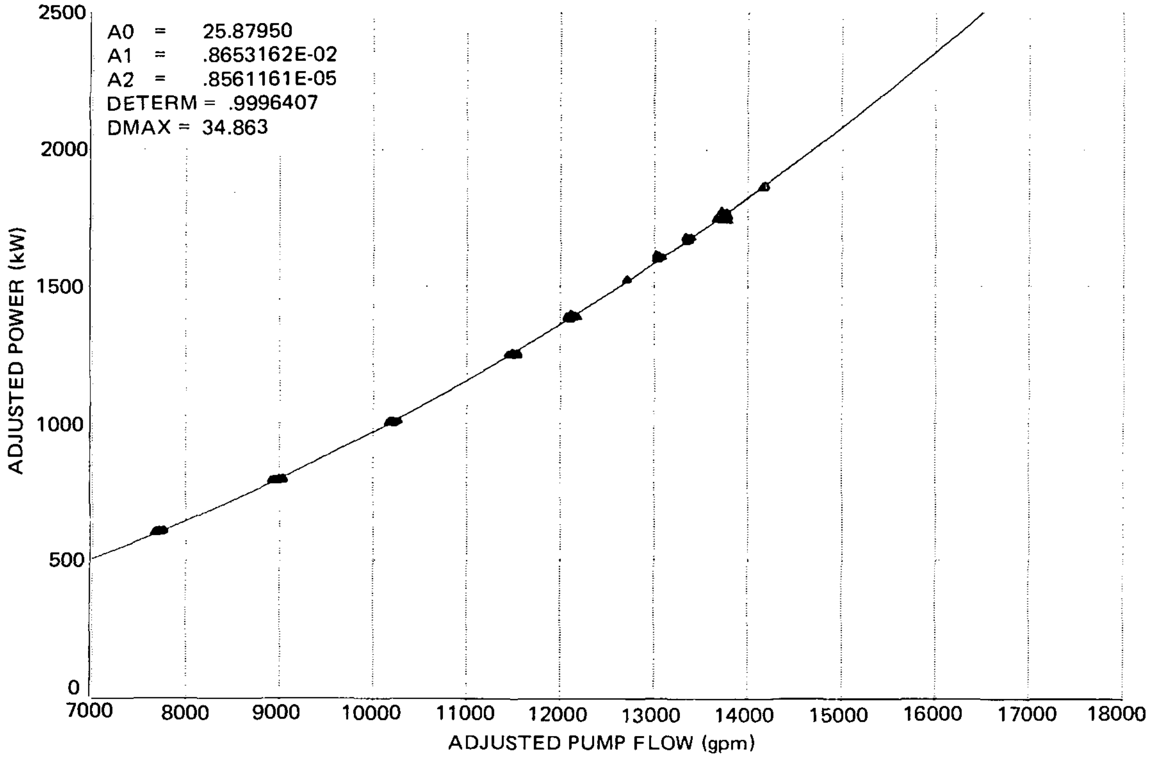
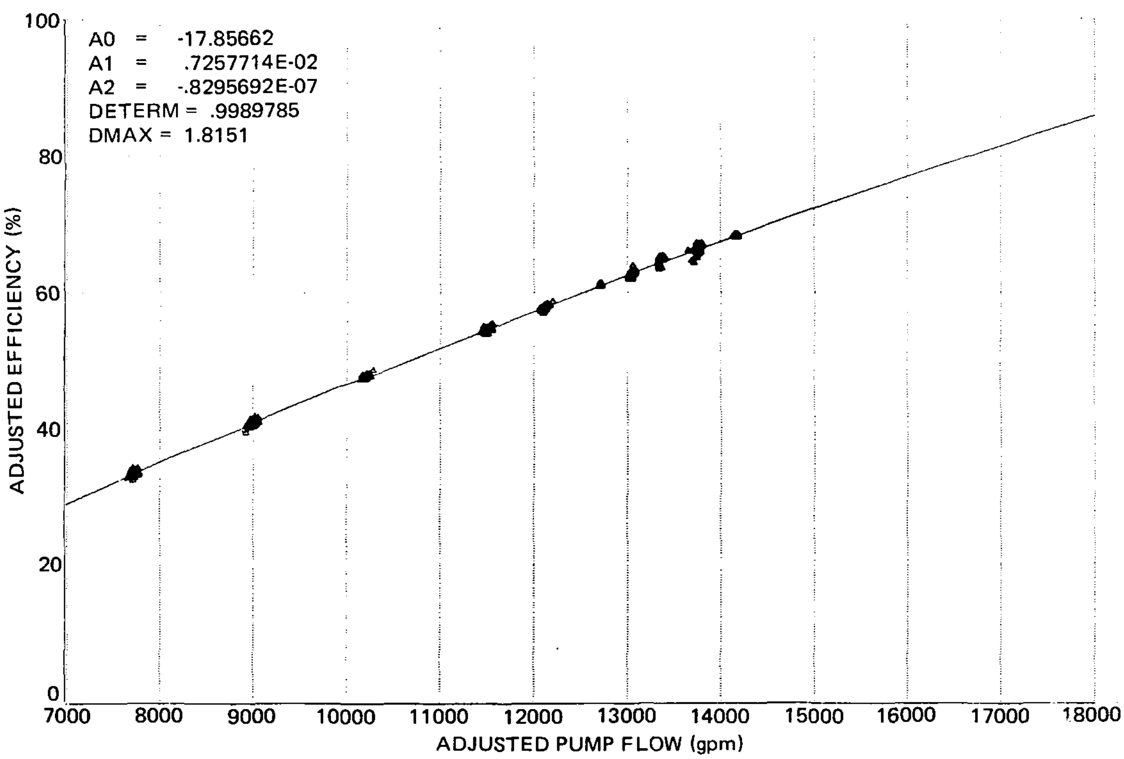


Figure 40. 750^{o}F R4 Speed Scan Data Plots (Sheet 1 of 2)



C. 750°F R4 SPEED SCAN, POWER



D. 750°F R4 SPEED SCAN, EFFICIENCY

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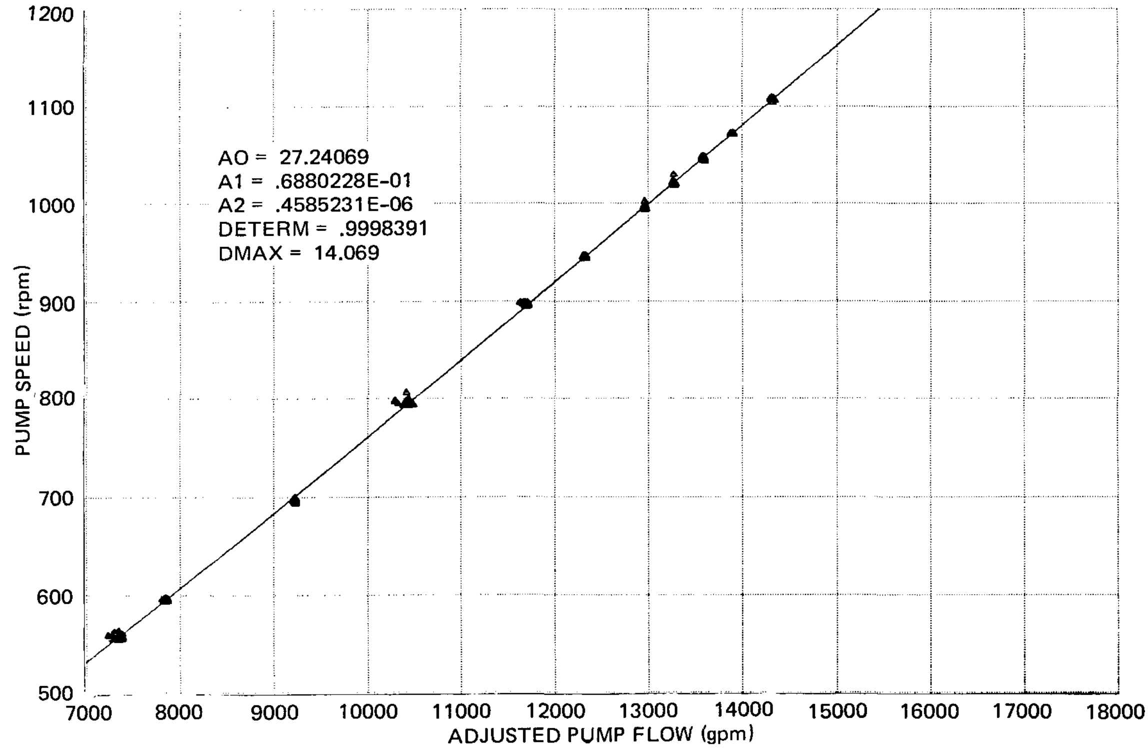
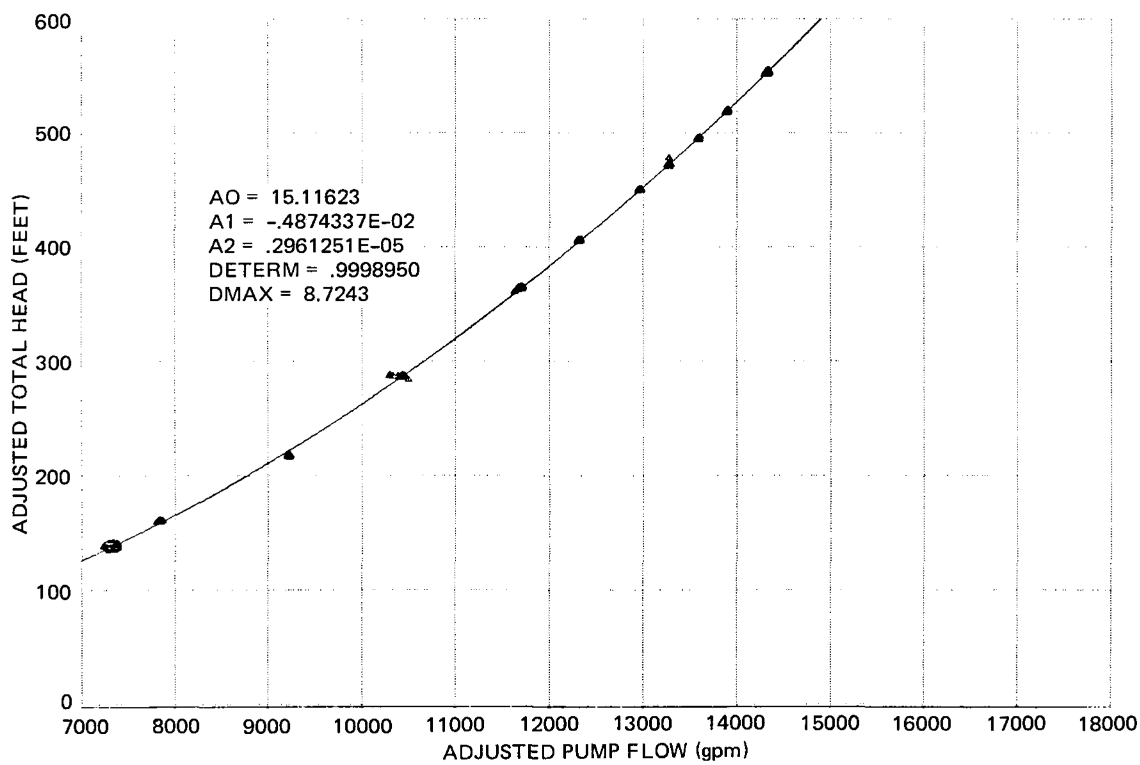
Figure 40. 750°F R4 Speed Scan Data Plots (Sheet 2 of 2)



A. 850°F R4 SPEED SCAN, SPEED



B. 850°F R4 SPEED SCAN, HEAD

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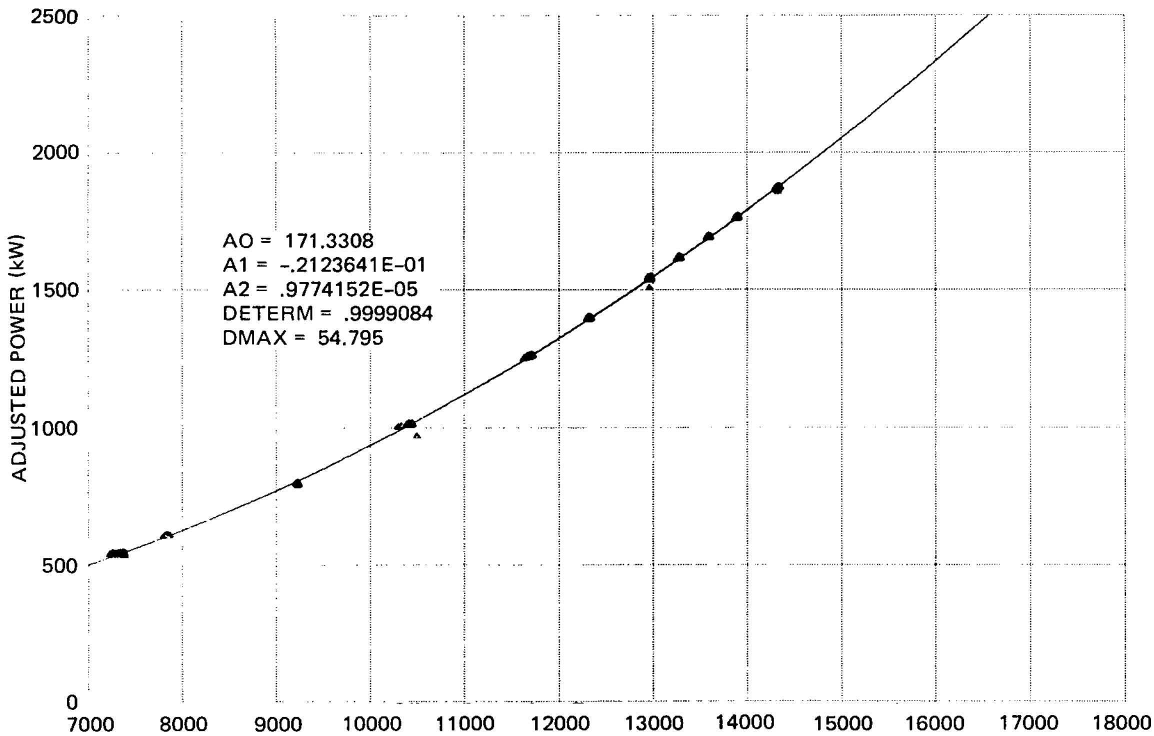
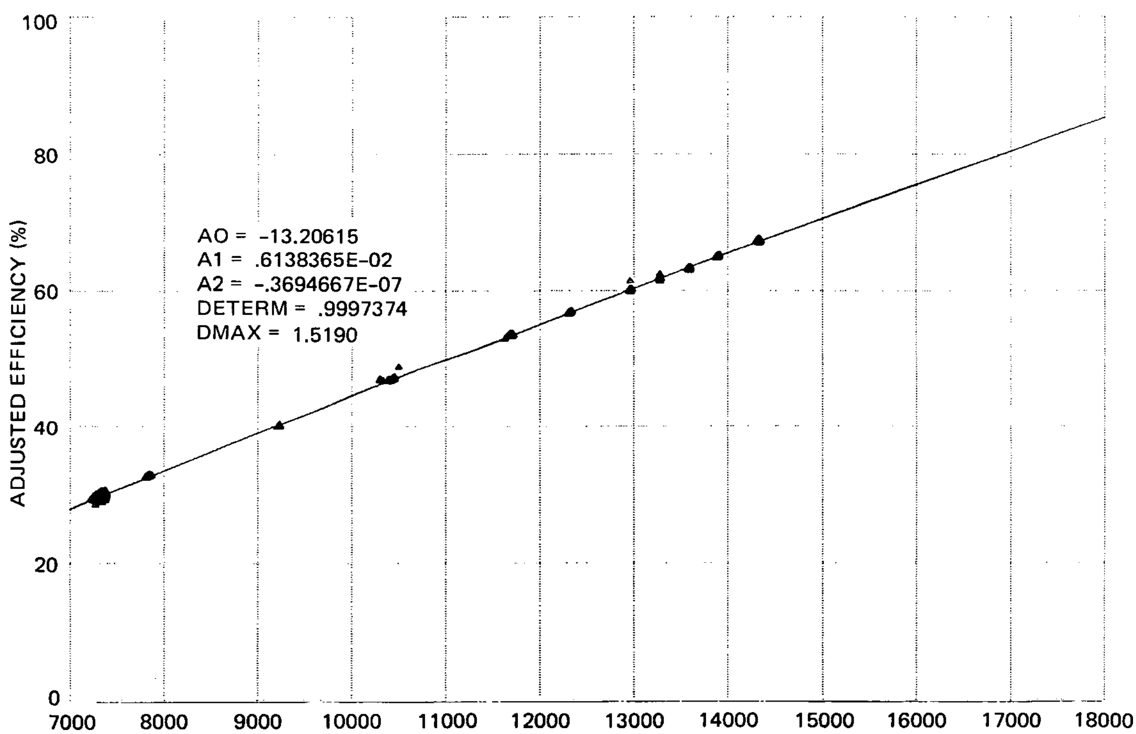
Figure 41. 850°F R4 Speed Scan Data Plots (Sheet 1 of 2)



C. 850°F R4 SPEED SCAN, POWER



D. 850°F R4 SPEED SCAN, EFFICIENCY

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Figure 41. 850°F R4 Speed Scan Data Plots
(Sheet 2 of 2)

and computed efficiency vs pump flow are presented as Figures 42a through 42d, respectively, for the R4 speed scan and as Figures 43a through 43d, respectively, for the R5 speed scan.

The 950°F flow scan data for head, power consumption, and efficiency vs pump flow are presented as Figures 44a through 44c, respectively.

The R4 and R5 speed scans and the flow scan are also shown plotted in Figures 35a and 35b as the pump performance head and power map curves, respectively.

5. 1000°F and 1050°F R4 Speed Scans

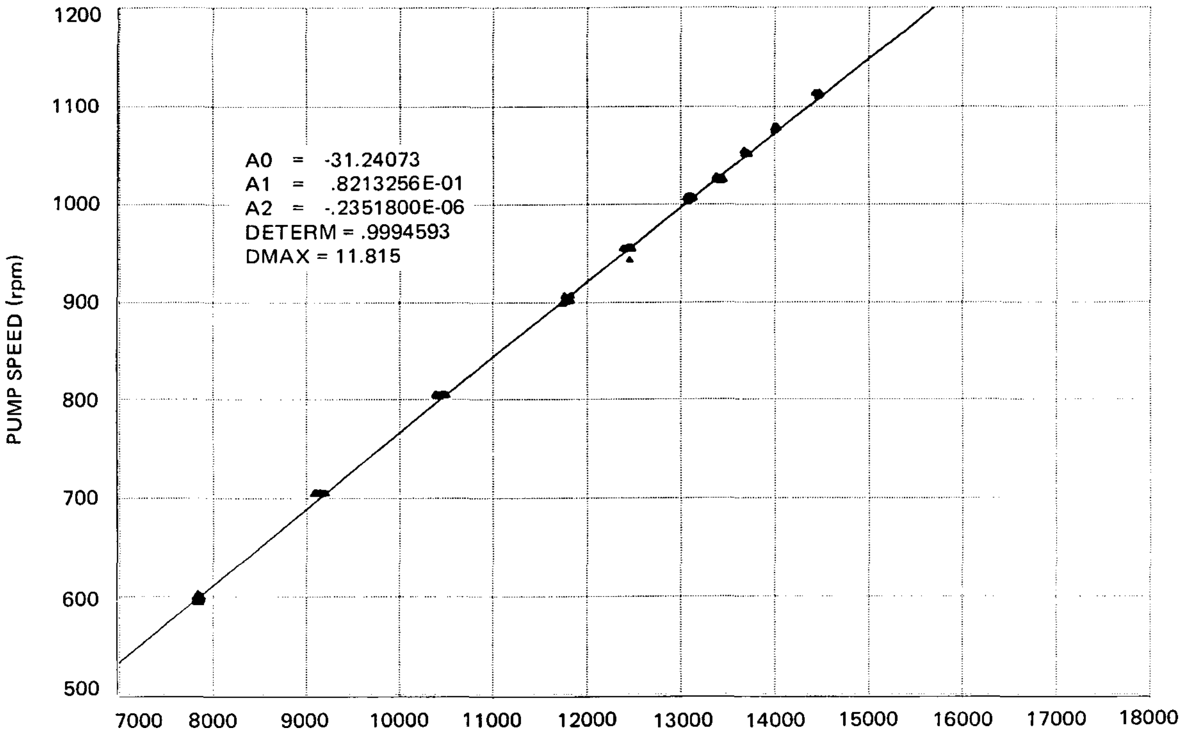
Data for the R4 speed scan performance parameters of pump speed, head, power consumption, and computed efficiency vs pump flow are presented as Figures 45a through 45d, respectively, for the 1000°F test and as Figures 46a through 46d for the 1050°F test.

6. *Cavitation Performance*

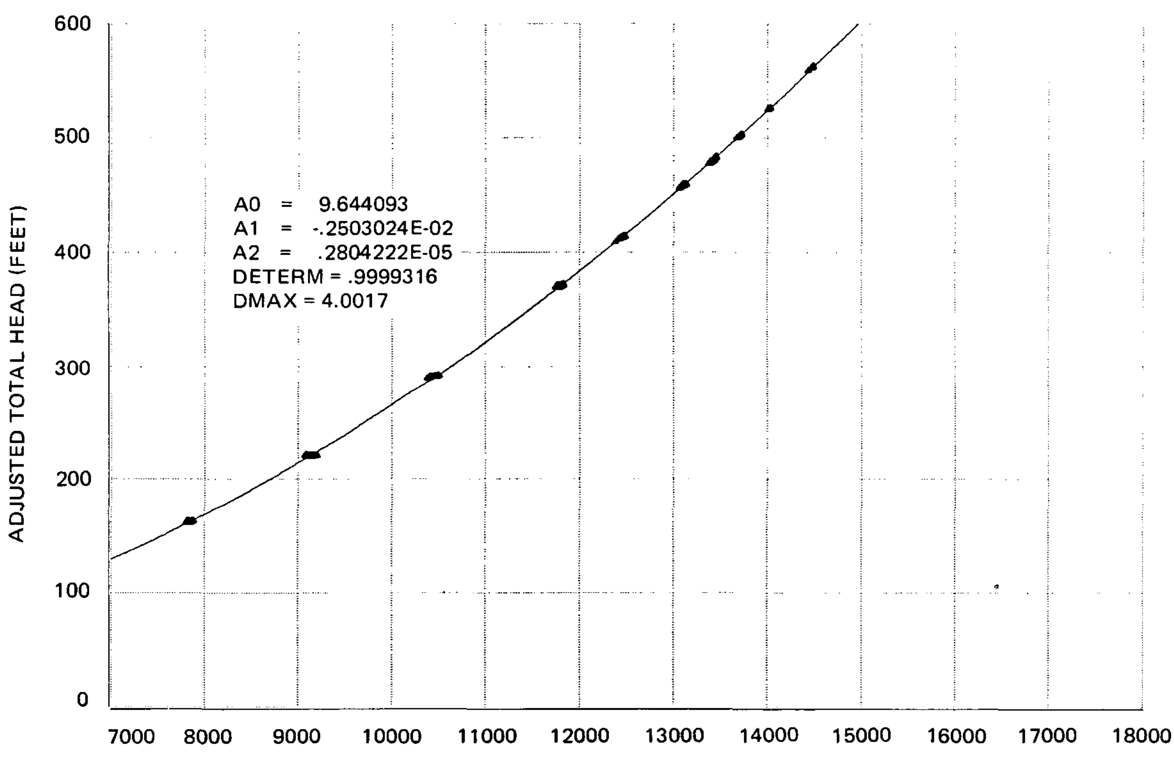
Purpose — The purpose of the cavitation test was to determine the critical NPSH required to cause a 3% head loss from measured head at 60 ft NPSH. The pump was to be operating at the design speed (1110 rpm) and design flow rate of 14,500 gpm (0.9148 m^3/s). NPSH was referenced to the inducer blade tip elevation.

Test Description — The targeted 3% head drop was not achieved. The cavitation test data in Figure 47 show that ∿2.1% head drop was realized. There were sufficient data acquired to confidently predict that the critical net positive suction head would be 11.3 ft (3.44 m) at the extrapolated 3% head drop.

The test was terminated prematurely due to what was considered to be excessive cavitation at the facility pressure reduction device (PRD). A loud noise reminiscent of rocks passing through the flow loop was emitted by the PRD during the cavitation phase.



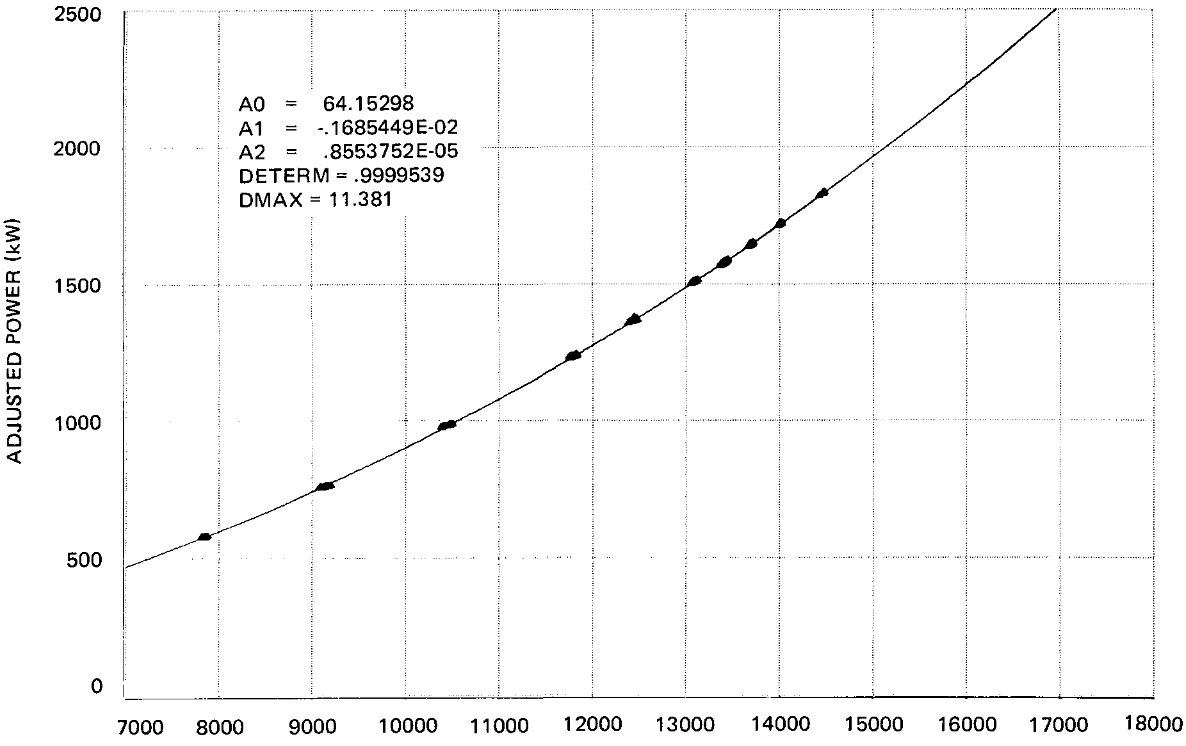
A. 950°F R4 SPEED SCAN, SPEED



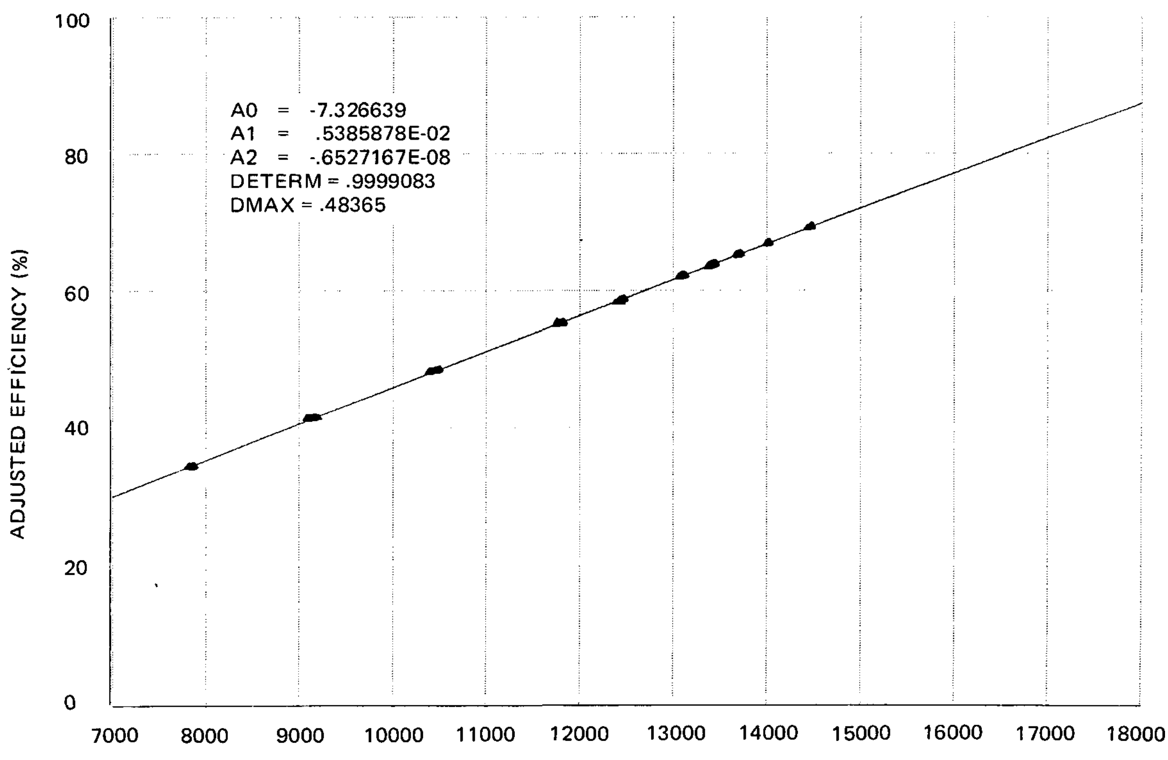
B. 950°F R4 SPEED SCAN, HEAD

ETEC-43985

Figure 42. 950°F R4 Speed Scan Data Plots (Sheet 1 of 2)



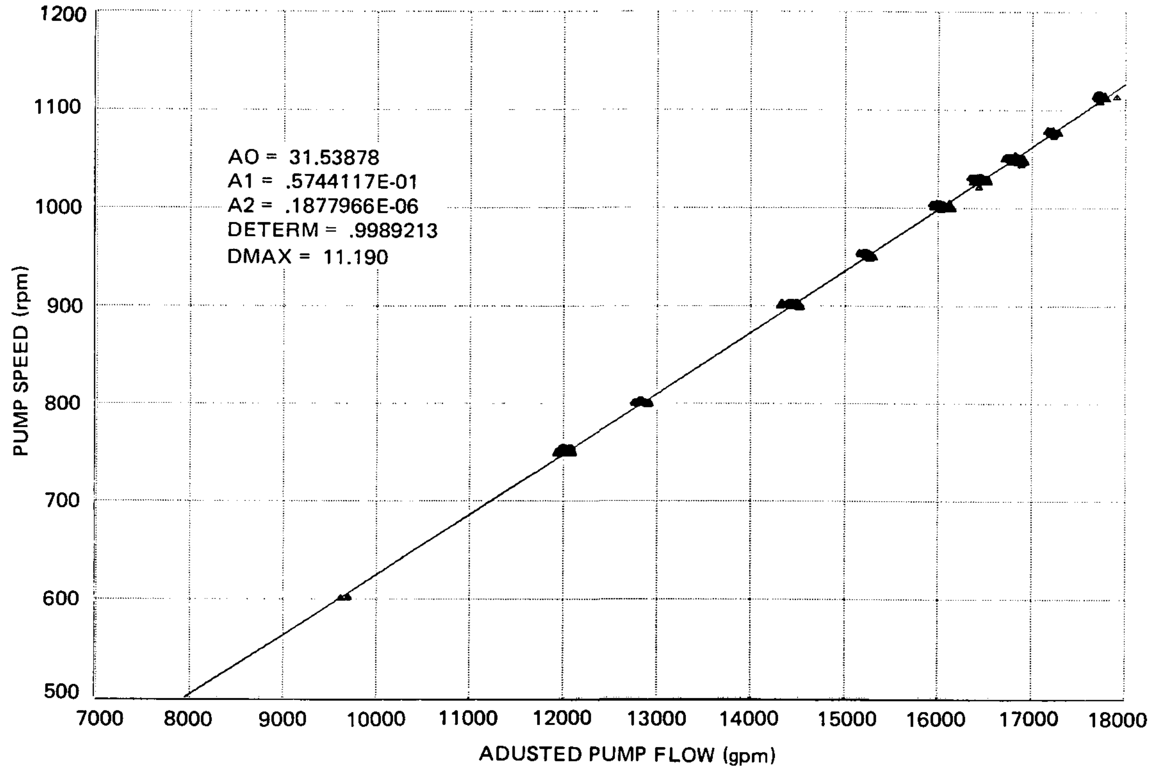
C 950°F R4 SPEED SCAN, POWER



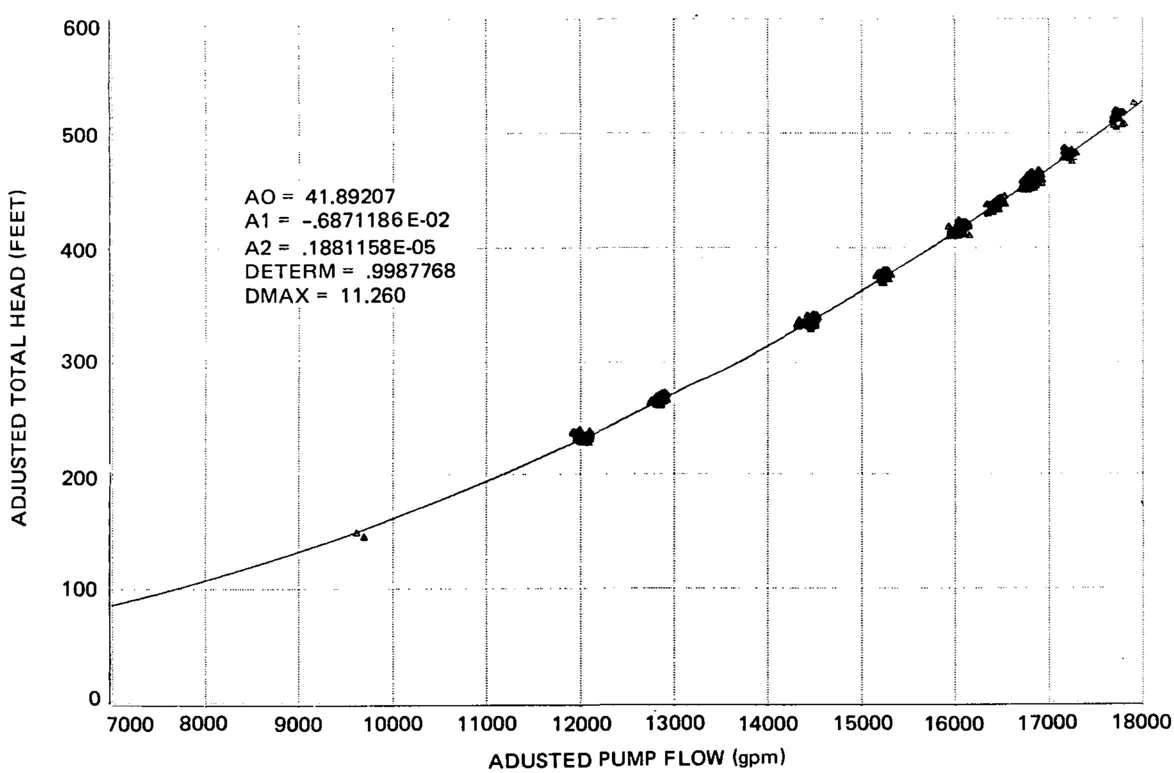
D. 950°F R4 SPEED SCAN, EFFICIENCY

ETEC-43986

Figure 42. 950°F R4 Speed Scan Data Plots (Sheet 2 of 2)



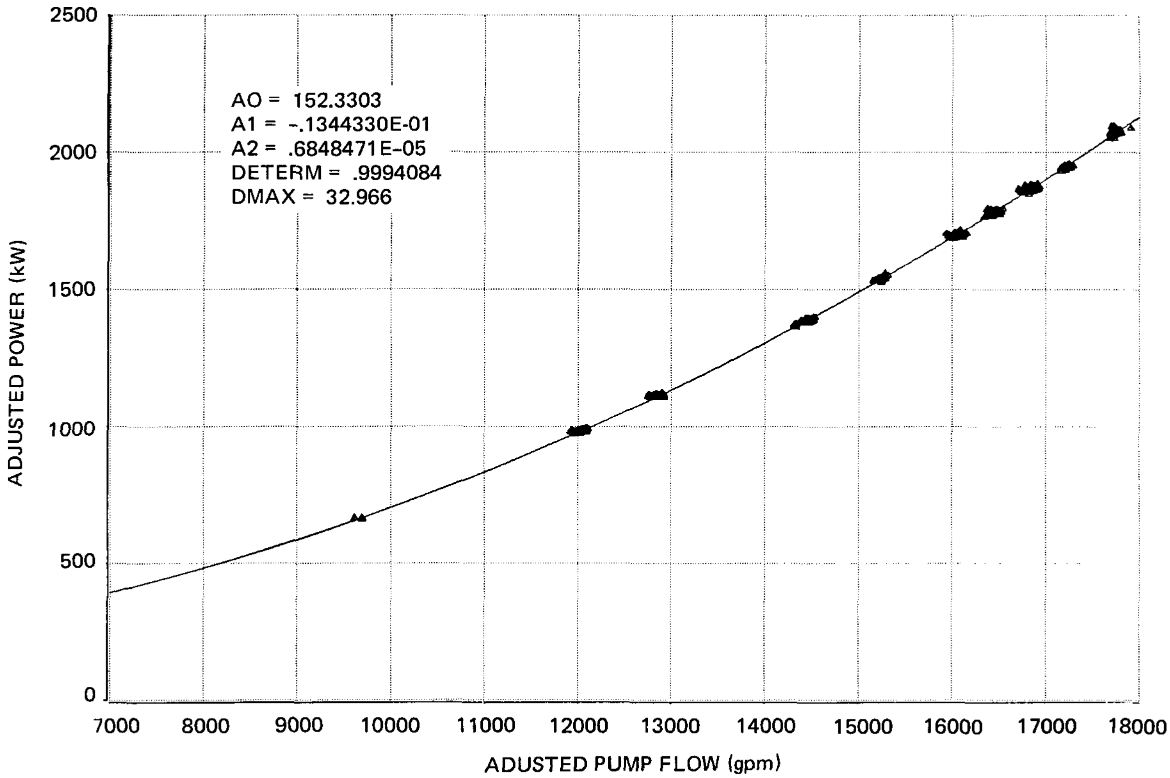
A. 950°F R5 SPEED SCAN, SPEED



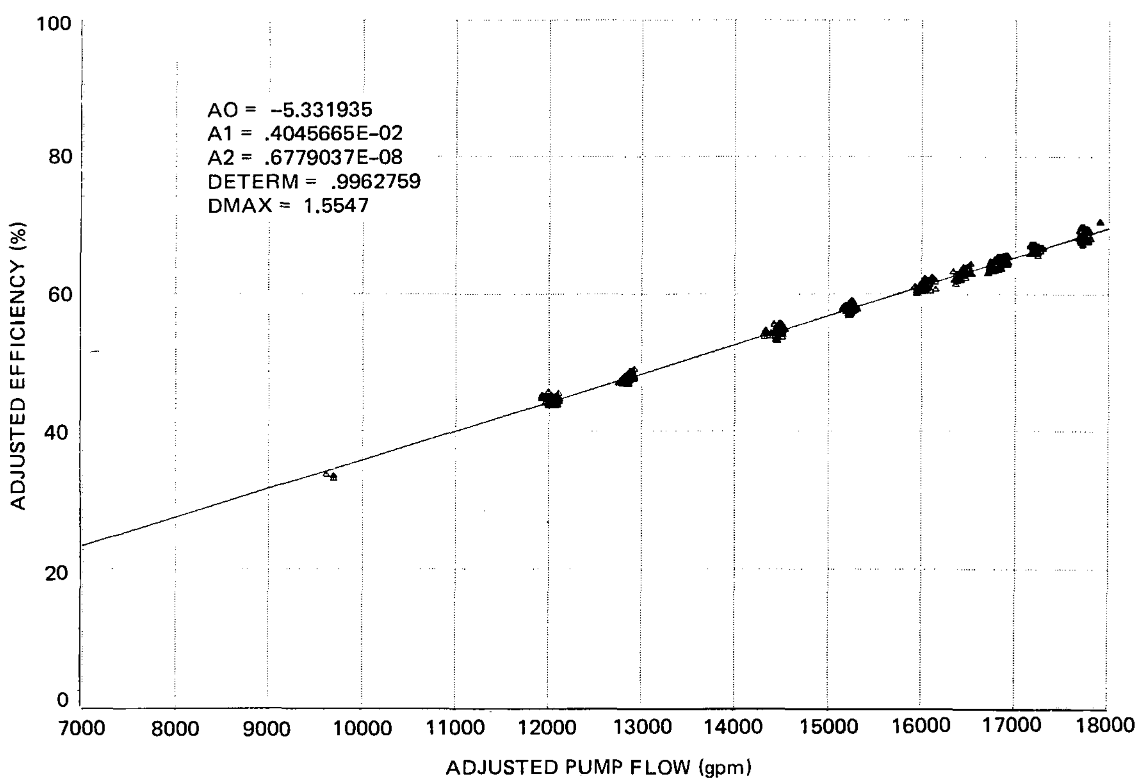
B. 950°F R5 SPEED SCAN, HEAD

ETEC-43987

Figure 43. 950°F R5 Speed Scan Data Plots (Sheet 1 of 2)



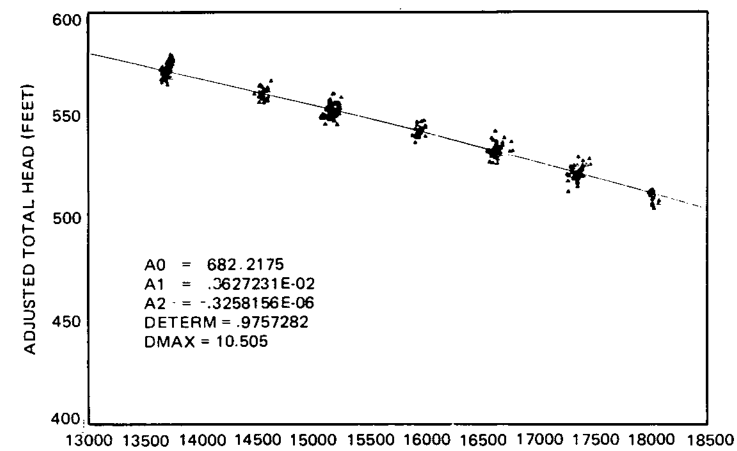
C. 950°F R5 SPEED SCAN, POWER



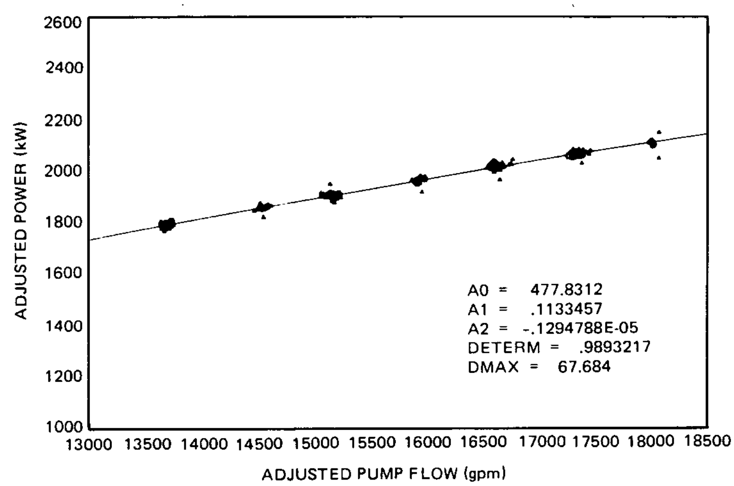
D. 950°F R5 SPEED SCAN, EFFICIENCY

ETEC-43988

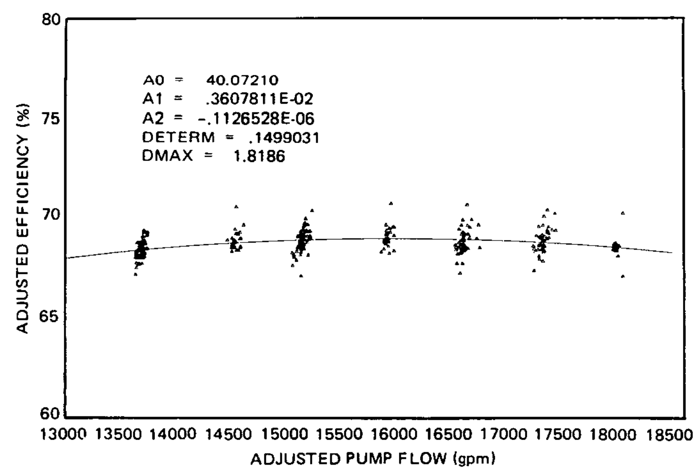
Figure 43. 950°F R5 Speed Scan Data Plots (Sheet 2 of 2)



A. 950°F FLOW SCAN, HEAD



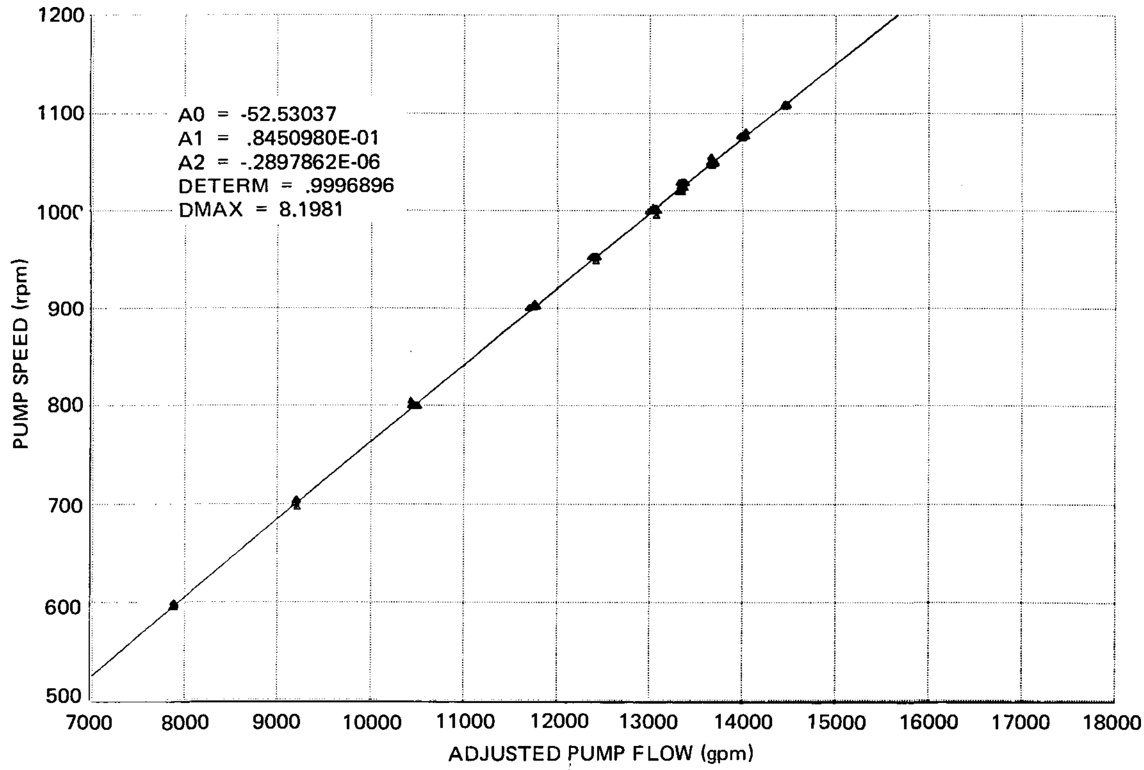
B. 950°F FLOW SCAN, POWER



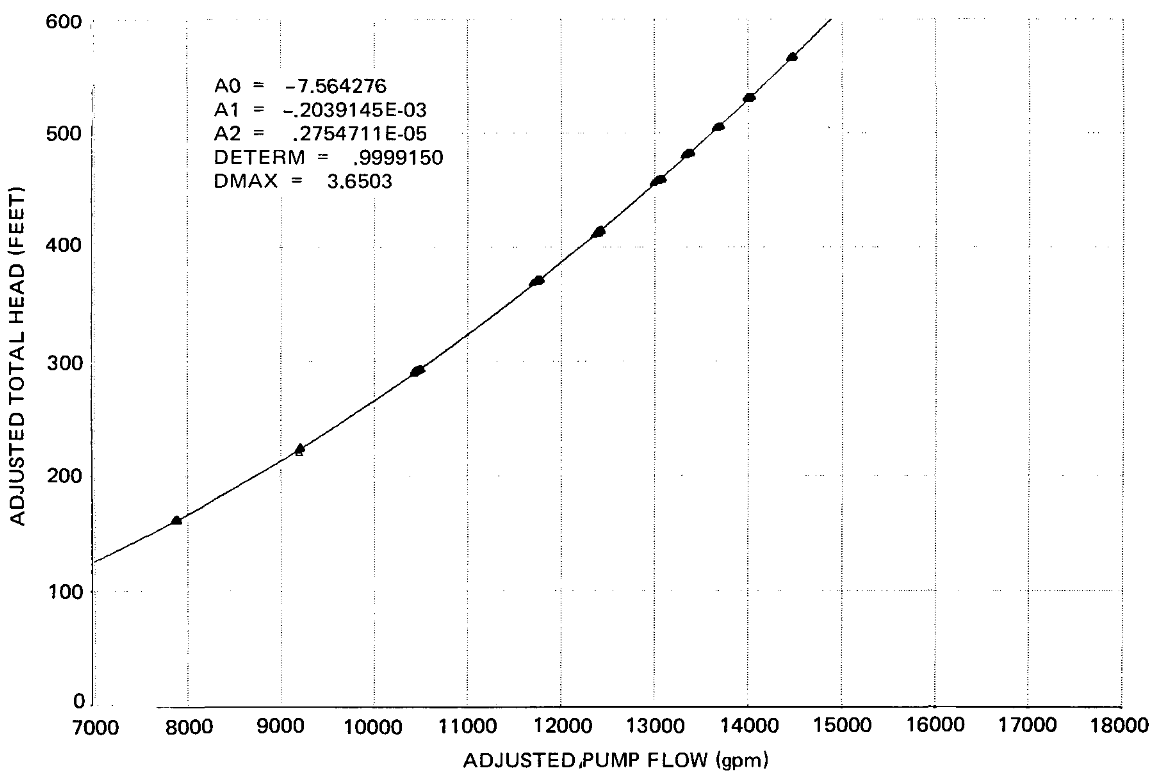
C. 950°F FLOW SCAN, EFFICIENCY

ETEC-43989

Figure 44. 950°F Seven-Point Flow Scan Data Plots



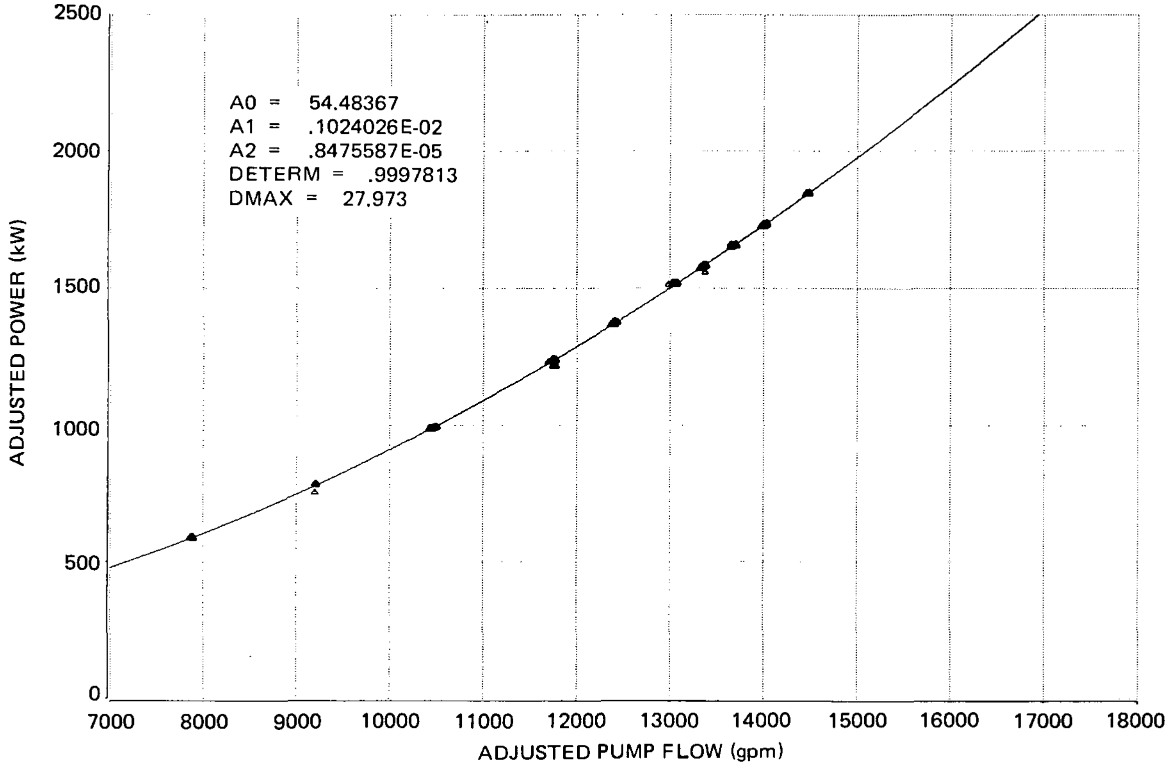
A. 1000°F R4 SPEED SCAN, SPEED



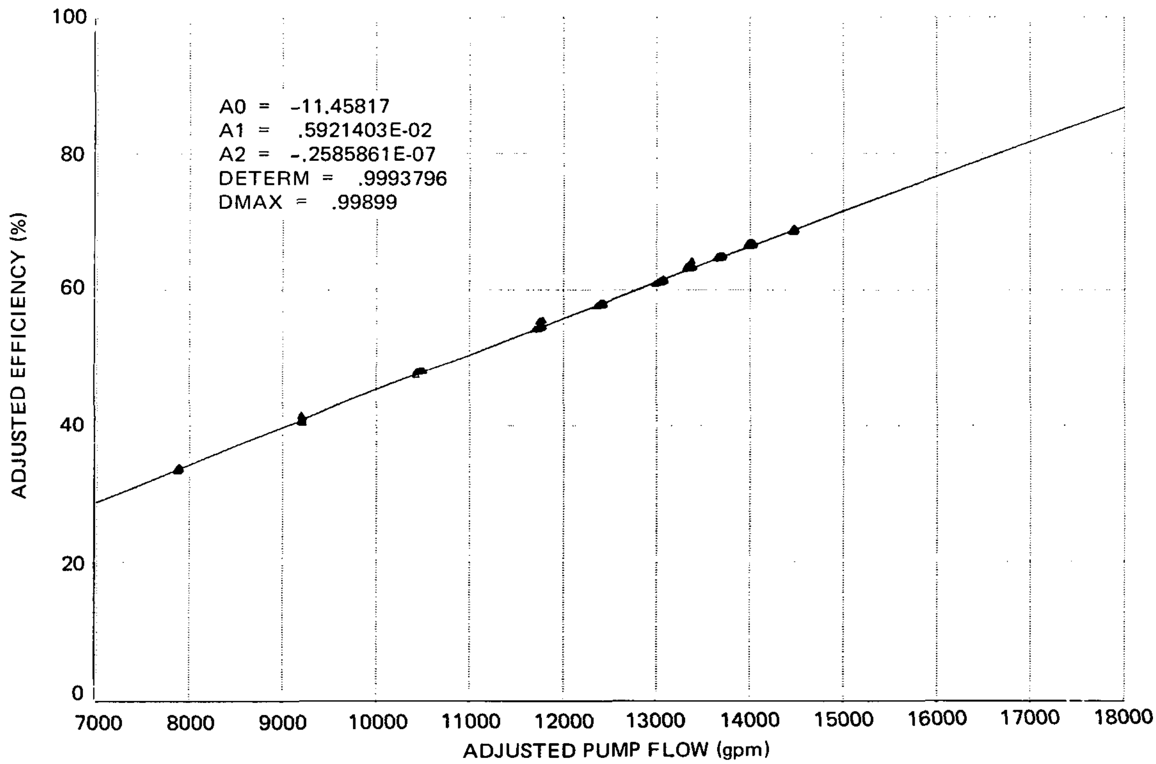
B. 1000°F R4 SPEED SCAN, HEAD

ETEC-43990

Figure 45. 1000°F R4 Speed Scan Data Plots (Sheet 1 of 2)



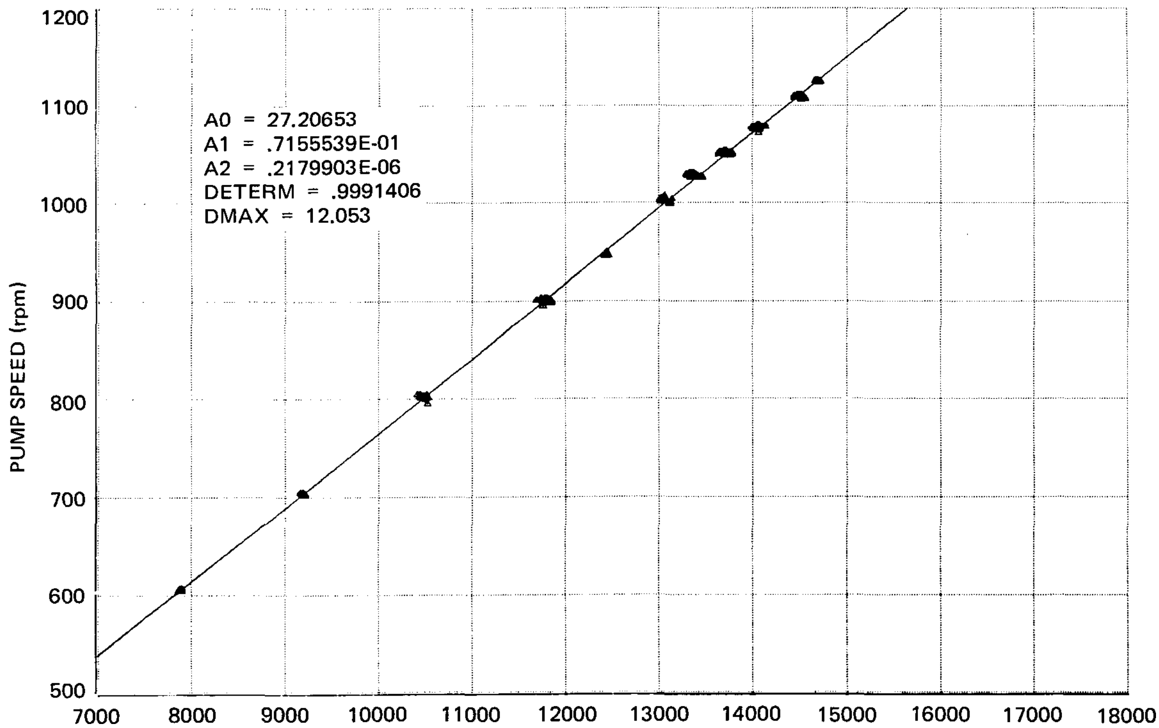
C. 1000°F R4 SPEED SCAN, POWER



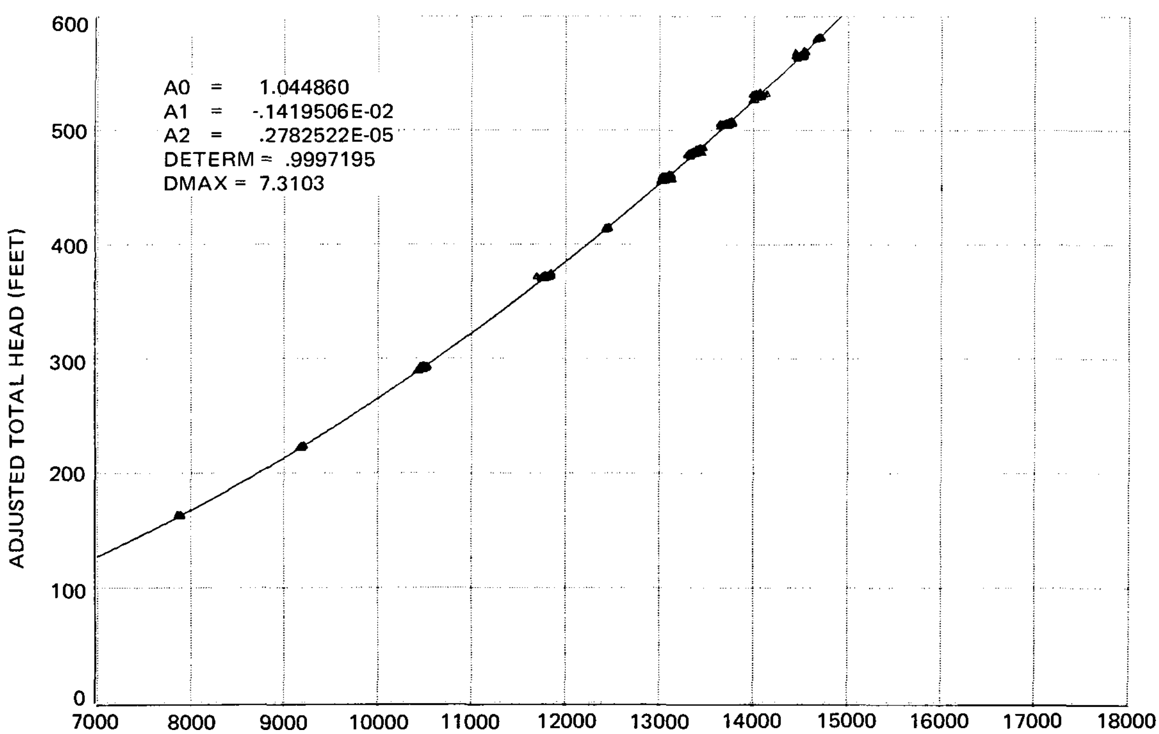
D. 1000°F R4 SPEED SCAN, EFFICIENCY

ETEC-43991

Figure 45. 1000°F R4 Speed Scan Data Plots (Sheet 2 of 2)



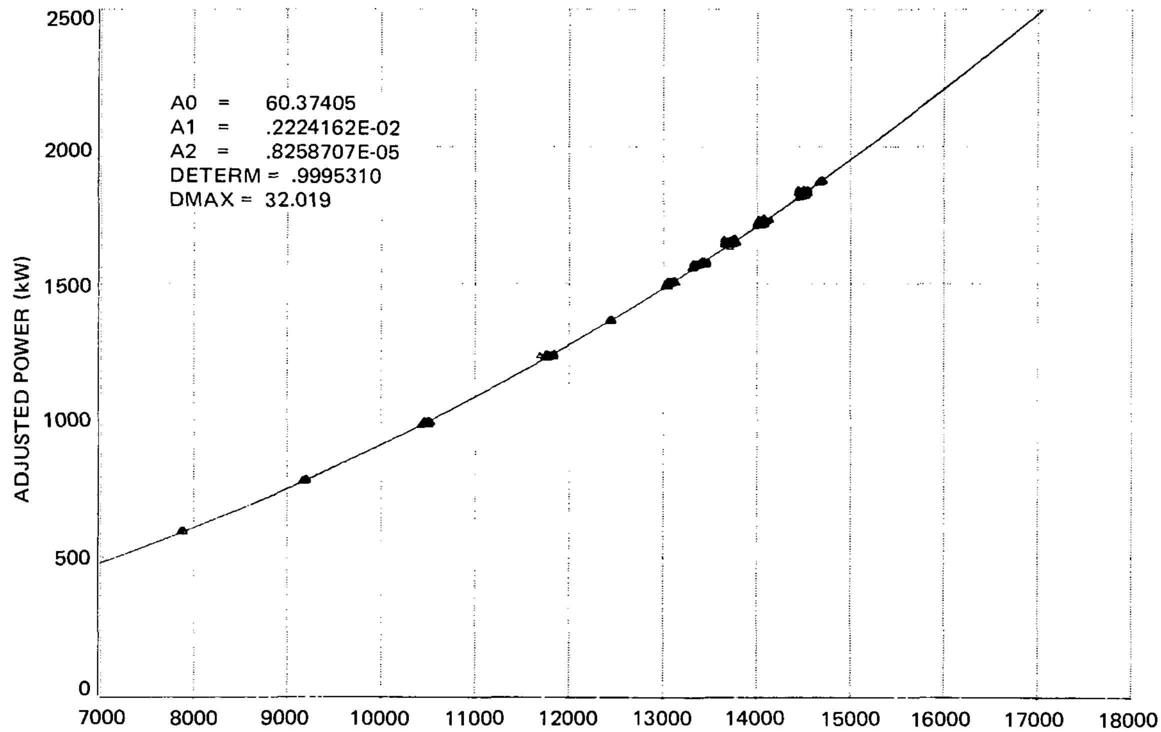
A. 1050°F R4 SPEED SCAN, SPEED



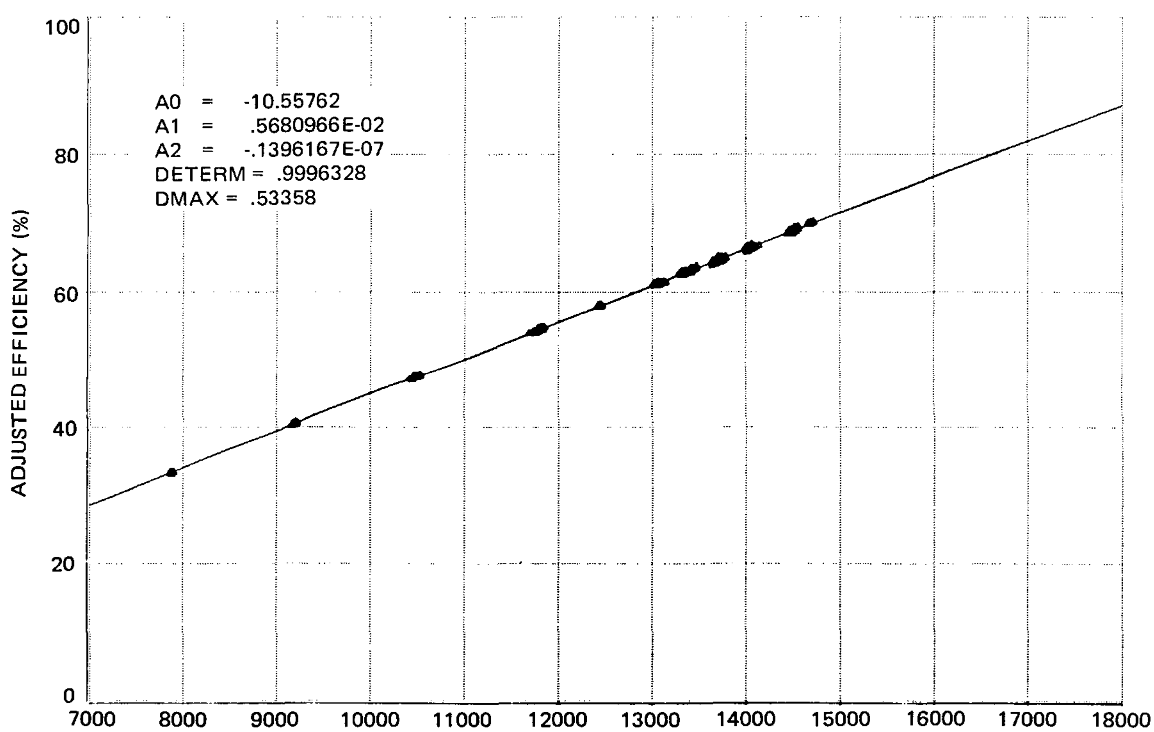
B. 1050°F R4 SPEED SCAN, HEAD

ETEC-43992

Figure 46. 1050°F R4 Speed Scan Data Plots (Sheet 1 of 2)



C. 1050°F R4 SPEED SCAN, POWER



D. 1050°F R4 SPEED SCAN, EFFICIENCY

ETEC-43993

Figure 46. 1050°F R4 Speed Scan Data Plots (Sheet 2 of 2)

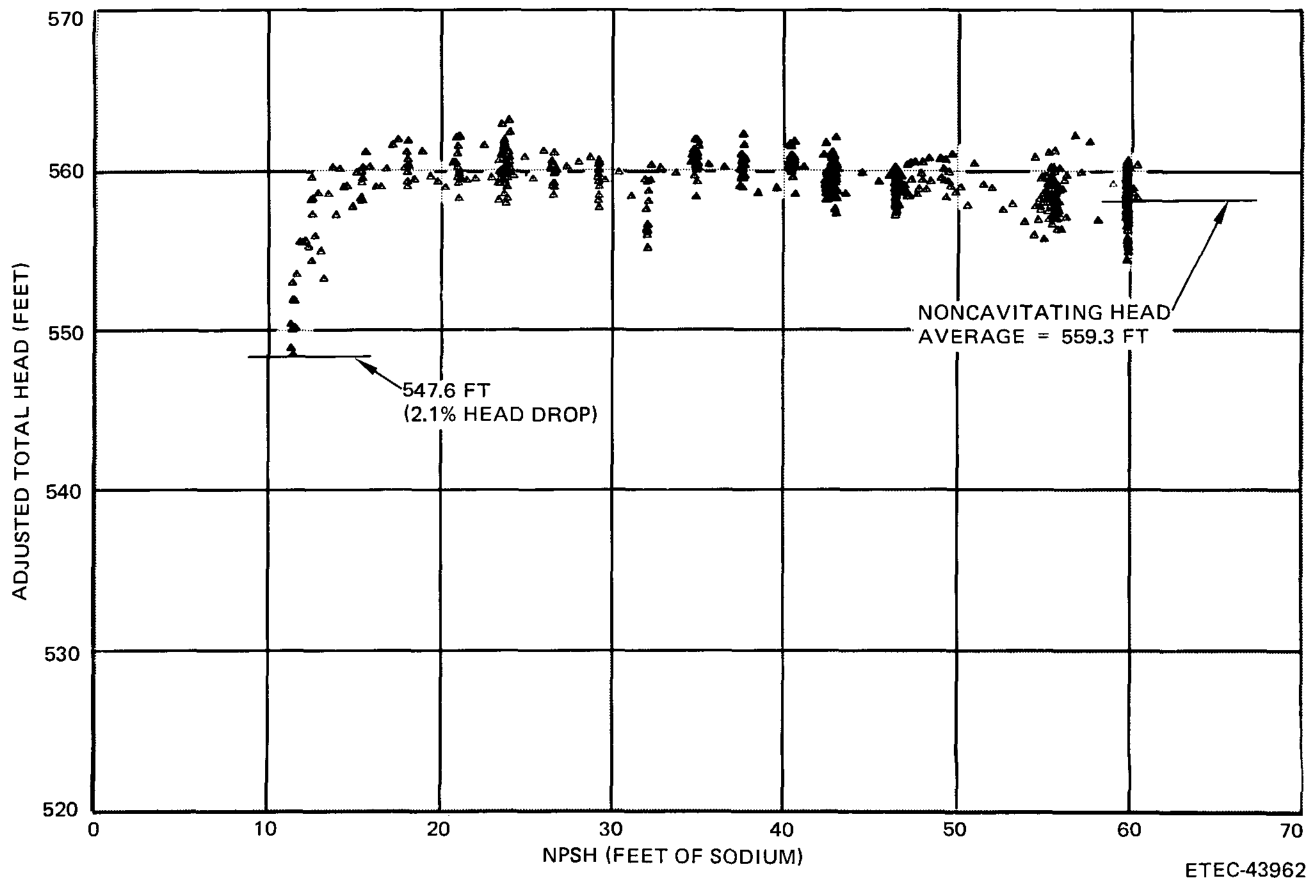
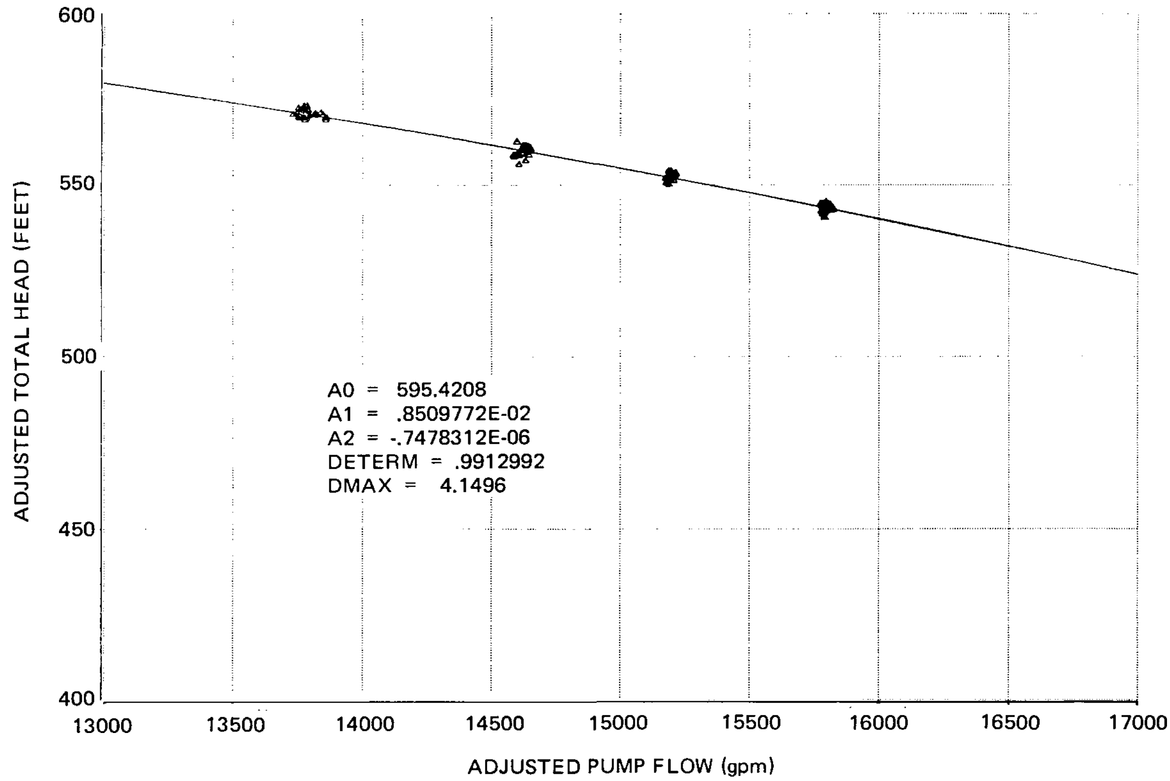


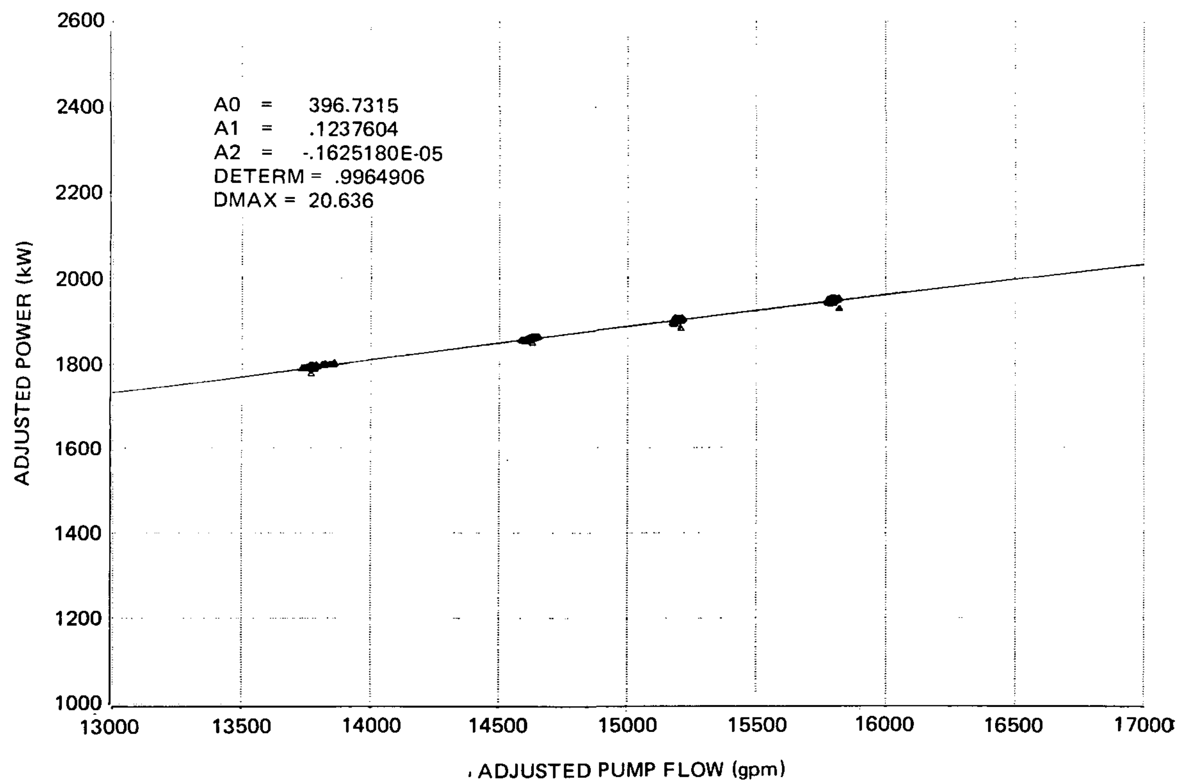
Figure 47. 950^{O}F Cavitation Test Data Plot

The initial flow rate and the NPSH for the cavitation test were determined using the techniques described in Appendix D. A flow scan was performed prior to the cavitation test to calibrate the pump and facility at the same conditions as those at which the cavitation test was to be run.

The total head and power consumption curves vs flow rate for the four-point flow scan are shown as Figures 48a and 48b, respectively. The head-vs-flow data for the four-point calibration flow scan were used to establish the initial operating point such that the flow rate would be 14,500 gpm (0.9148 m^3/s) at the 3% head drop limit. The required initial cavitation test flow rate was determined to be 14,690 gpm (0.9268 m^3/s) using the technique described in Appendix B.



A. HEAD vs FLOW



B. POWER vs FLOW

ETEC-43994

Figure 48. Cavitation Pretest Four-Point Flow Scan

The noncavitating baseline head was established by operating for 1 h at the following conditions:

NPSH	60 ft (18.29 m)
Speed	1110 rpm
Flow rate	14,690 gpm (0.9268 m^3/s)
Temperature	950°F (510°C)
Sodium level	125 in. (3.175 m) above impeller
Total head	559.3 ft (170.47 m)

The baseline head for noncavitation was verified by operating at NPSH of 80 ft (26.21 m) for 1 h at the same speed, flow rate, temperature, and sodium level. The developed total head for NPSH of 86 ft (26.21 m) was 559.2 ft (170.44 m).

Reduction of NPSH was accomplished by two methods: The first was to lower the sodium level in the pump tank from 125 in. (3.175 m) (normal operating level) to 48 in. (1.219 m) above the impeller centerline. The second method was to reduce the pump tank cover gas pressure below atmospheric pressure by means of a vacuum pump.

The cover gas pressure was reduced in small increments, ∿1-2 psi (6.89-13.79 kPa), until cavitation was achieved. The time history of cover gas pressure for the test is shown in Figure 49. The cover gas pressure had to be reduced to 1.6 psia (6.89 kPa) to achieve 2.1% head drop.

F. DIURNAL EFFECT ON PERFORMANCE

After operating at steady-state conditions for some time, it became obvious that the performance parameters were fluctuating or drifting while the pump speed apparently remained essentially constant. A Hewlett-Packard time-interval counter coupled with a proximity probe to sense pump shaft rotation was used to determine a more accurate pump speed than could be achieved with the tachometer generator. A comparison of the pump speed (over a 24-h period) measured by the Hewlett-Packard

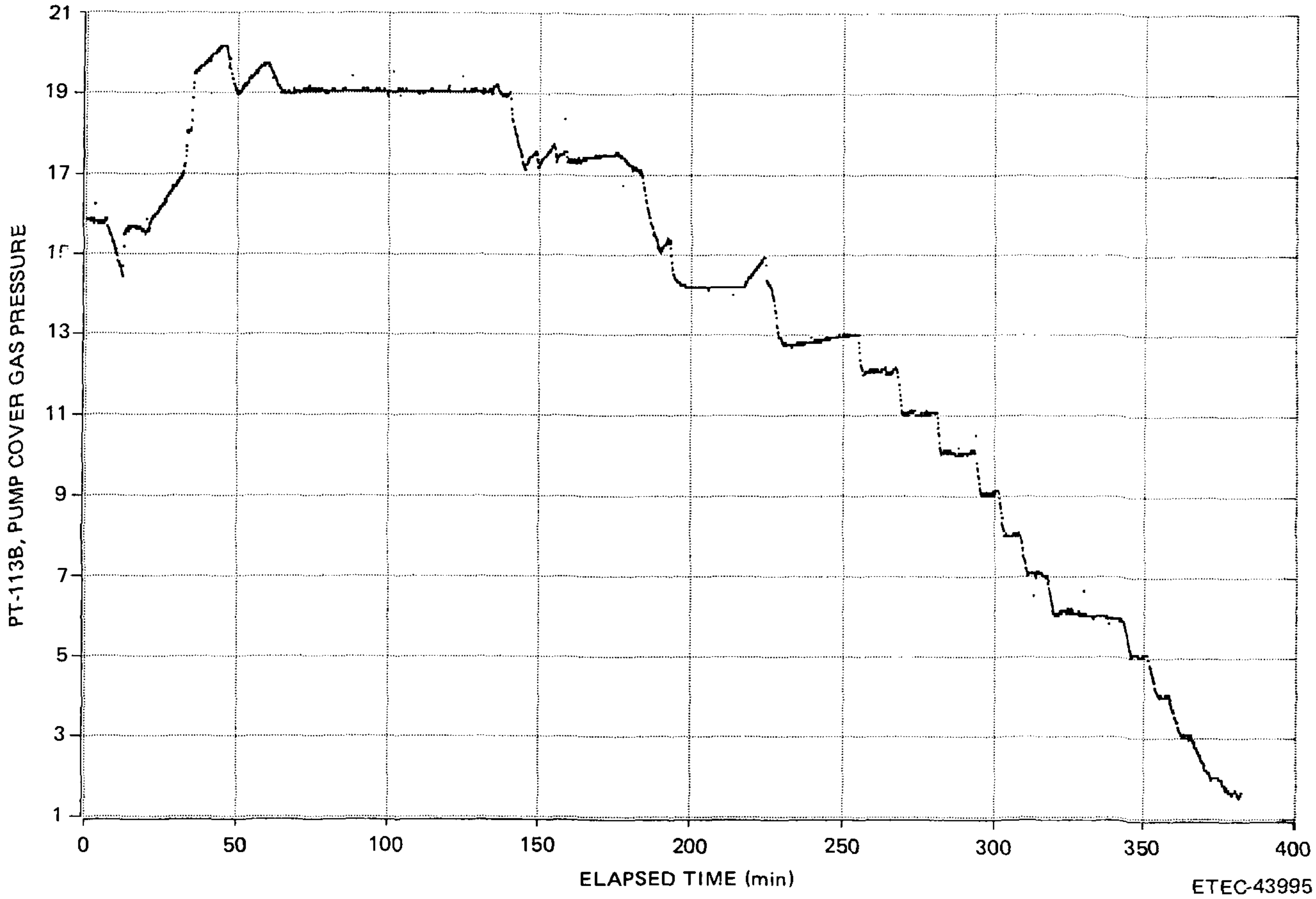


Figure 49. Cavitation Test Cover Gas Pressure History

counter (SE-HP) and the tachometer generator (SE-47) is shown in Figure 50. The apparent speed, as indicated by SE-47, shows a spread of only 0.09% around an average of 1110.5 rpm at the time noted. The actual speed, as indicated by SE-HP, varied only 0.5% maximum from the SE-47 average.

The speed controller was capable of maintaining pump speed such that the tachometer generator voltage output was reasonably constant. The voltage output of the tachometer generator was sent to a voltage divider circuit. The voltage signal provided to the SE-47 speed indicator was picked off the voltage divider. Since the performance parameters varied at an apparent constant speed (indicated by SE-47), it was concluded that the voltage output per revolution of the tachometer generator varied.

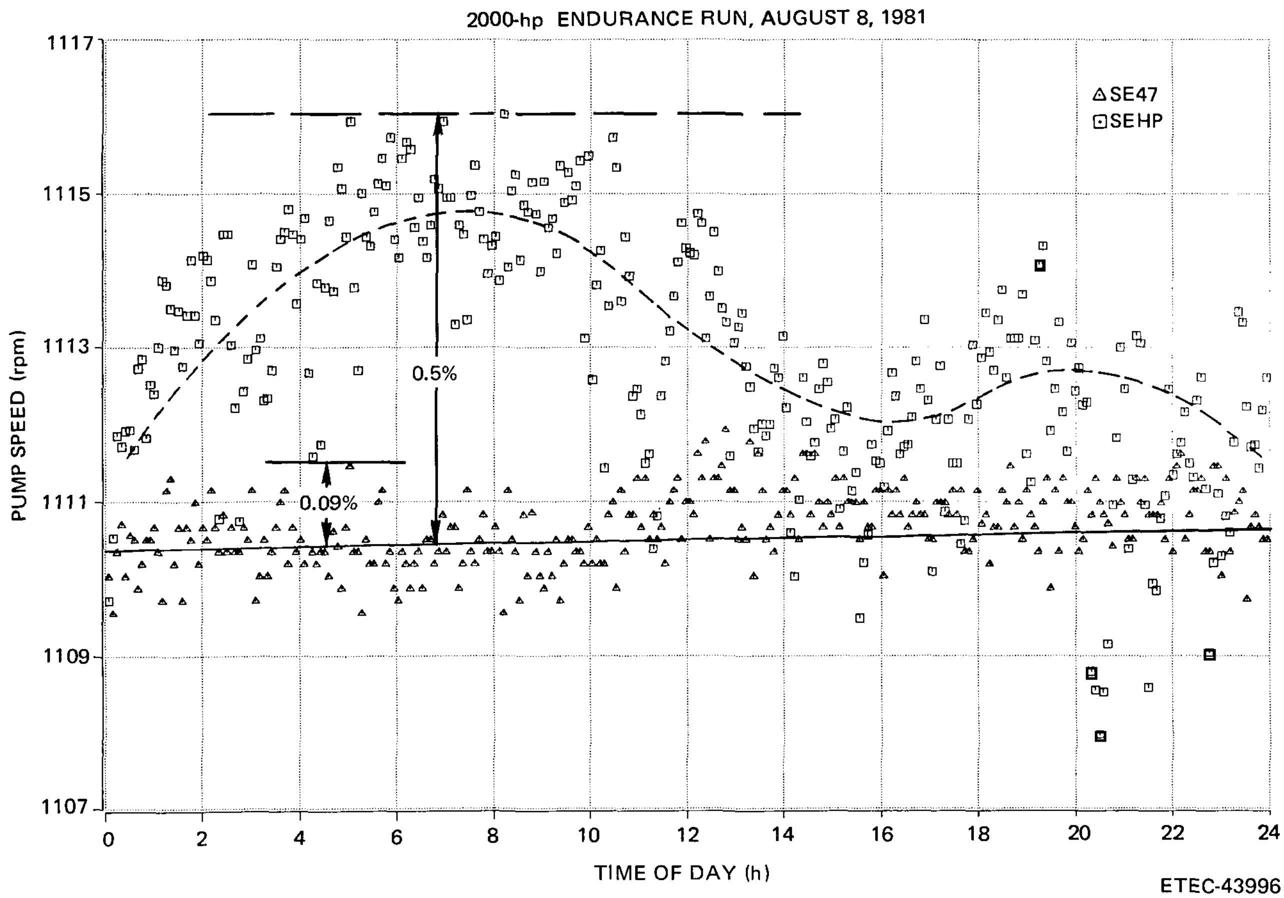


Figure 50. Comparison of SE-47 and SE-HP Speed Indicators

G. PUMP LUBE OIL CONSUMPTION

A tabulation of pump and motor lube oil consumption was maintained throughout the ISIP-II test program. The record of lube oil drainage and additions is shown in Table 9.

Table 9 shows that 28.59 gal (108.2 l) of lube oil were drained from the lower leakage reservoir. Added to that is 5.99 gal (22.7 l) drained from the windback housing, for a total of 34.58 gal (130.9 l) of oil leakage. Accounting for 25.89 gal (98.0 l) added to the lube oil supply tank gives a calculated net depletion in the lube oil supply tank of 8.69 gal (32.9 l). The observed oil level depletion from the sight gage was 11.5 in. (29.2 cm), which is equivalent to 8.80 gal (33.3 l). The difference in methods of accounting for lube oil tank

TABLE 9

PUMP LUBE OIL USAGE RECORD

Date	Oil Drained (gal)			Oil Added (gal)	Sight Gage (in.)		Average Oil Leakage Between Drainage Times (gal/day)		
	Lower Leak Reservoir	Windback Bottle	Total		Initial	Final	Lower Leak Reservoir	Windback Housing	Total
04-11-81	-	-	-	-	-	24.5	-	-	-
07-12-81	3.5	0.4	3.9	4.0	17	20	0.10	0.01	0.11
07-19-81	-	0.75	0.75	-	-	-	-	0.11	-
07-29-81	6.0	0.5	6.5	10.0	13	25.125	0.35	0.05	0.43
08-03-81	-	0.5	0.5	-	-	-	-	0.05	-
08-15-81	-	-	-	3.96	10.75	17.75	-	-	-
08-23-81	14.75	3.0	17.75	7.93	9.75	19.25	0.61	0.15	0.76
08-25-81	2.09	0.34	2.43	-	-	-	1.04	0.17	1.22
08-31-81	2.25	0.5	2.75	-	13	-	0.45	0.10	0.55
Totals	28.59 +	5.99 =	34.58 (drained)	25.89 (added)	11.5 (difference in level from start to end of test series)				

- Oil drained 34.58 gal
  Oil added -25.89 gal

  Net depletion from initial level 8.69 gal

- Observed start-to-end tank level difference

  (11.5 in.)(0.765 gal/in.) = 8.80 gal

- Oil inventory discrepancy: 8.80 gal (sight gage)
  -8.69 from inventory

  0.11 gal (unaccounted for)

depletion produces a net oil inventory discrepancy of 0.11 gal (6.4 l). The discrepancy in oil inventory is well within the accuracy of measurement capability.

The average leakage rates for the lower leak reservoir and the windback housing are included in Table 9. The average leakage rates are calculated for the periods between drainage times. There is an apparently higher leakage rate during the period from August 23, 1981, through August 25, 1981, than during other periods. Figure 31 shows that the highest average leakage rate occurred during the period when the HEDL coastdown tests were performed. The HEDL coastdown test series consisted of 32 main motor coastdowns and 16 pony motor coastdowns.

The HEDL coastdown tests were performed to support the HEDL FFTF pump test program. Excessive oil leakage had been observed at HEDL during pump main motor coastdown.

Operation of Lube Oil Skid — Specific operating data on the lube oil skid were requested by HEDL[11] in support of a HEDL noise abatement program, the Aurora Turbine Pump H05 operation. The requested data were obtained and transmitted to HEDL.[12]

H. VIBRATION SPECTRA PLOTS

1. General Description

a. Accelerometers

Eleven accelerometers were used to measure the vibration amplitude of the test article components.

Three Endevco high-frequency accelerometers were mounted at each of the following locations: the bottom of the pump tank, the bearing seal housing, and the main motor mount. Each of the groups of three accelerometers was oriented to provide vibration measurements in three perpendicular horizontal and vertical axes.

Two low-frequency Kaman accelerometers were also mounted on the bottom of the pump tank. They provided vibration measurements on the horizontal axis through the centerline of, and at a right angle to, the suction nozzle.

Figure 51 shows locations and nomenclature of accelerometers and other pump tank instrumentation. Orientation of the accelerometers and the maximum allowable displacement are presented in Table 10.

TABLE 10

ACCELEROMETER DESCRIPTIONS

Nomenclature	Description	Maximum Value: Displacement (in.), p-p
VE-06Z	Motor vibration — in-line suction, radial	0.030
VE-06X	Motor vibration — 90-deg suction, tangential	
VE-06Y	Motor vibration — vertical	
VE-08Z	Seal housing vibration — in-line suction, radial	0.005-trip, 0.002-alarm at 0-20 Hz
VE-08X	Seal housing vibration — 90-deg suction, tangential	
VE-08Y	Seal housing vibration — vertical	
VE-07Z	Tank vibration — in-line suction, radial	0.010 at 5-20 Hz
VE-07X	Tank vibration — 90-deg suction, tangential	0.002 above 20 Hz
VE-07Y	Tank vibration — vertical	
VE-10A	Tank vibration — 90-deg suction, tangential	
VE-10B	Tank vibration — in-line suction, radial	

b. Vibration Spectra Plots

Output signals from the accelerometers were recorded on analog tape to permit off-line analysis. The facility data acquisition system included the capability to produce on-line vibration spectra plots of the output of any accelerometer.

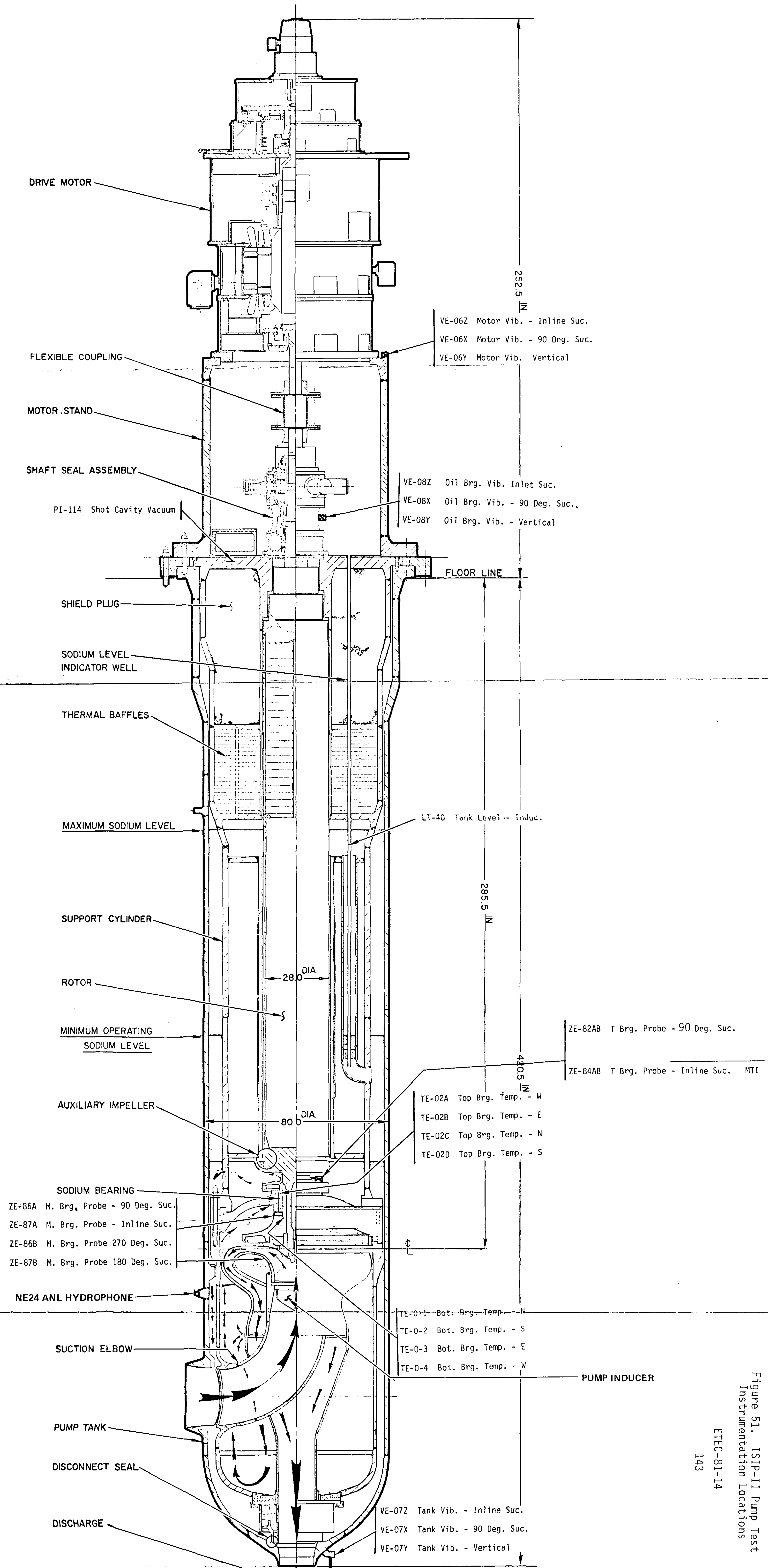


Figure 51. ISIP-II Pump Test Instrumentation Locations

Accelerometer output signals were displayed as decibels (dB) vs frequency. A scaled reference of one g_{rms} of acceleration was chosen as the reference and, therefore, one g_{rms} measured represents zero dB from the equation:

$$dB = 20 \log_{10} \frac{g_m}{g_r} \qquad \text{(IX-6)}$$

where

g_m = measured acceleration (rms)
g_r = reference of one g of acceleration (rms)
dB = decibel.

Solving for g_m,

$$g_m = 10^{\frac{dB}{20}}$$

Knowing acceleration and frequency, the vibration displacement can be calculated from the equation:

$$d = \frac{27.68\ (g_m)}{f^2} \qquad \text{(IX-7)}$$

where

d = p-p displacement (in.)
f = frequency of acceleration (Hz).

Equation IX-7 was taken from Reference 13 and rearranged for rms units directly. Displacement, peak-peak, can also be found by use of a vibration nomograph such as that shown in Figure 52.

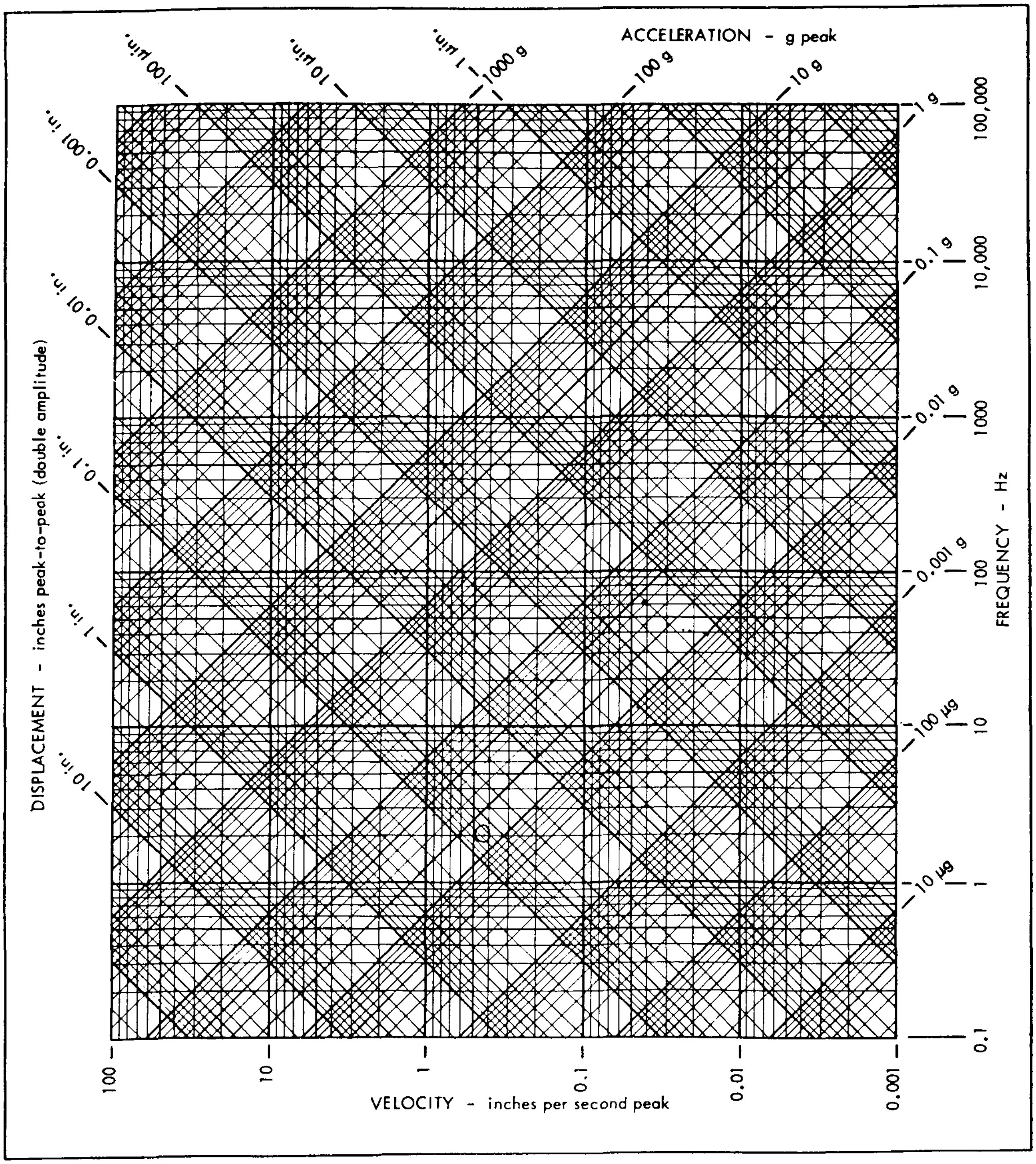


Figure 52. Vibration Nomograph

Vibration spectra plots were provided for rms-averaged low- and high-frequency ranges. The low-frequency plot consisted of 16 rms averages plotted on a frequency scale of zero to 100 Hz. The high-frequency plot consisted of 69 rms averages plotted on a frequency scale of zero to 5000 Hz. The decibel scale of both frequency-range plots was -80 to zero dB. The equivalent acceleration range is 100 μg to 1 g_{rms}, respectively.

2. Test Results

Typical low-frequency vibration spectra plots are shown in Figures 53a through 53c. The plots are for the $950^{o}F$ ($510^{o}C$) R4 speed scan, but they are typical in general appearance of all low-frequency plots.

In these low-frequency plots, it can be seen that apparent vibration levels appear at several discrete frequencies. However, several of the apparent vibration peaks can be readily identified as electrical noise. The peaks at zero Hz are induced by the spectrum analyzer. The peaks at 60 Hz are electrical power system noise.

Another electrical noise peak appears at the slip frequency. The slip frequency is defined as the frequency of the voltage and current induced in the wound rotor of the pump drive motor. The frequency increases as the motor speed decreases and approaches zero when the motor speed approaches synchronous speed (1200 rpm). The slip frequency can be calculated from the expression:

$$f_{slip} = \frac{(N_{sync.} - rpm) \times (3 \text{ pairs of poles})}{(60 \text{ sec/min})} \qquad \text{(IX-8)}$$

where

$N_{sync.}$ = 1200 rpm (synchronous motor speed).

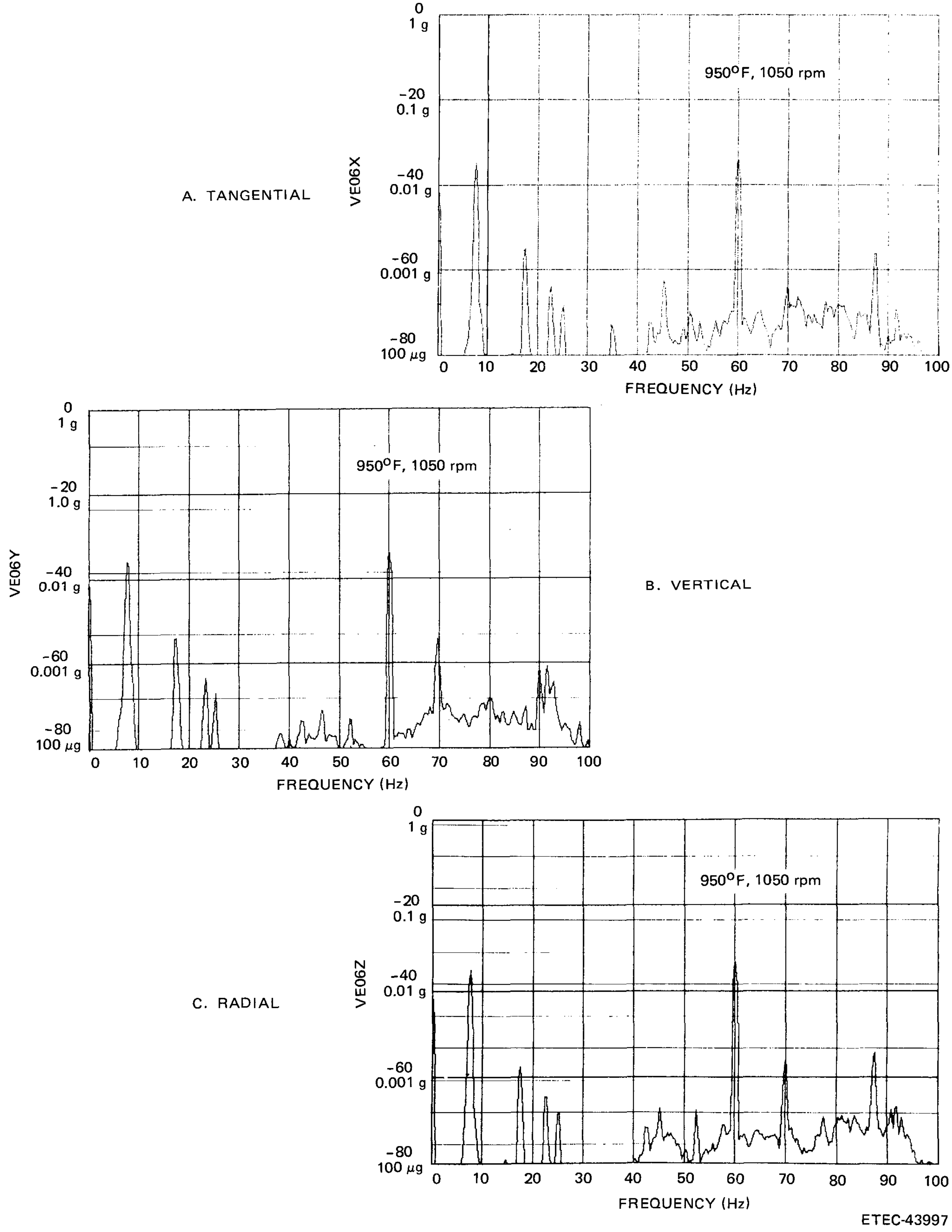


Figure 53. Typical Low-Frequency Motor Stand Vibration Data Plots

Slip frequencies for the speed scan operating points are shown in Table 11. For example, the slip frequency at 1050 rpm is 7.5 Hz. It appears as a relatively large amplitude apparent vibration peak, as seen in the low-frequency plots.

The run frequency at operating speed is calculated from:

$$f_{run} = \frac{N}{60\ s/min} \qquad \text{(IX-9)}$$

where

F_{run} = the run frequency (Hz)

N = the shaft speed (rpm).

For example, the run frequency at 1050 rpm is 17.5 Hz and is easily identifiable on the aforementioned low-frequency plots.

Harmonics of the slip frequency and other vibration frequencies also are evident on the plots. All other vibration frequencies have a lower amplitude than the primary run frequency. Low acceleration g levels at higher frequencies result in vibration amplitudes that are orders of magnitude smaller than the primary run frequency. The low-g-level, high-frequency vibrations are, therefore, not considered. The high-frequency plots for the 950^{o}F (510^{o}C) R4 speed scan will be presented in Figures 54a through 54c.

Motor Stand Vibration — Motor stand vibration data for the 950^{o}F (510^{o}C) R4 speed scan are presented in Table 11. This range of data is typical of all the tests run.

It can be seen from Table 11 that the vibration displacement recorded by VE-06X (tangential) is generally slightly higher than that recorded by the radial or vertical accelerometers. However, even the highest values recorded (less than 200 μin.) are trivial compared to the maximum allowable displacement of 0.030 in.

TABLE 11

MOTOR-STAND VIBRATION DATA
950°F R4 SPEED SCAN

Speed (rpm)	Run Frequency (Hz)	Slip Frequency (Hz)	VE-06X		VE-06Y		VE-06Z	
			Amplitude (g, rms)	Displacement p-p (μ in.)	Amplitude (g, rms)	Displacement p-p (μ in.)	Amplitude (g, rms)	Displacement p-p (μ in.)
600	10.0	30.0	500μ	137	170μ	47	160μ	44
700	11.66	25.0	700μ	141	230μ	46	270μ	54
800	13.33	20.0	0.0011	170	310μ	48	310μ	48
900	15.0	15.0	0.019	-	0.019	-	0.018	-
950	15.83	12.5	0.0016	175	470μ	51	350μ	38
1000	16.66	10.0	0.0018	178	0.001	99	600μ	59
1025	17.08	8.75	0.0015	148	0.0015	148	0.0012	118
1050	17.50	7.5	0.0018	178	0.002	197	0.0014	138
1110	18.5	4.5	-	-	-	-	-	-

Notes:

1. The run frequency vibration and the slip frequency noise are additive at 900 rpm. Amplitude shown is, therefore, not true vibration amplitude, and vibration displacement was not calculated.
2. Maximum allowable vibration is 0.030 in. p-p.
3. Amplitude data are for run frequency vibration.

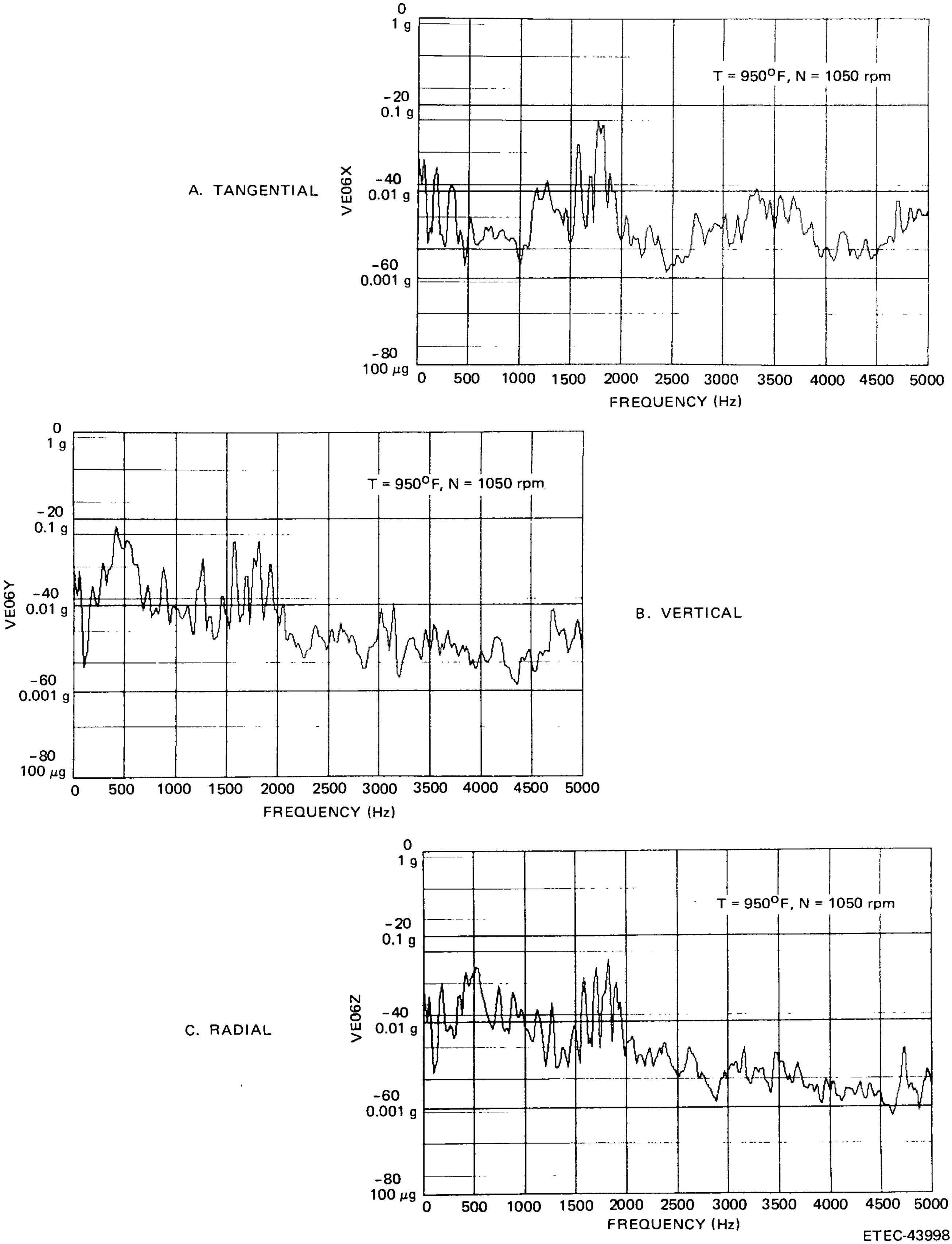


Figure 54. Typical High-Frequency Motor Stand Vibration Data Plots

Low- and high-frequency vibration spectra plots for the 1050-rpm point of the 950°F (510°C) R4 speed scan are presented in Figures 53a through 53c and Figures 54a through 54c for the tangential, vertical, and radial axes, respectively. Both the low- and high-frequency on-line plots are presented.

It was concluded that the motor-stand vibration levels were well within reason and that no motor-stand vibration problems existed.

Bearing Seal Housing Vibration — Typical bearing seal housing vibration data are presented in Table 12. The data presented are from the 700°F (371.1°C) flow scan. The maximum vibration displacement measured was on the order of 50 μin. The alarm was set to 0.002 in. and the trip level set to 0.005-in. displacement. Measured vibration levels never approached the alarm or trip set points.

Typical low- and high-frequency vibration spectra plots at 1110 rpm are shown in Figures 55a and 55b. The slip frequency noise again tends to overshadow the actual run frequency vibration.

It was concluded that the bearing seal housing vibration level was well within the allowable limits.

Pump Tank Vibration — Typical pump tank vibration displacement data from the Endevco radial accelerometer (VE-07Z) are shown in Table 13. The data were taken from the 950°F (510°C) R5 speed scan. A typical low-frequency vibration spectra plot for the radial accelerometer is shown in Figure 56a. The Endevco accelerometers mounted at this location consistently show a higher level of background vibration than do those at the motor end of the pump. The magnitude of the electrical induced noise is similar to the other Endevco accelerometers. This would lead one to suspect that the background noise was flow induced; however, the magnitude of the background noise did not correlate as expected with flow, which would indicate that it comes from some other undefined source.

TABLE 12

BEARING SEAL HOUSING VIBRATION DATA
700°F FLOW SCAN

Flow (gpm)	VE-08Y	
	Amplitude (g, rms)	Displacement p-p (μ in.)
13,500	630 μ	50
14,500	630 μ	50
15,000	600 μ	48
15,400	450 μ	36
16,500	450 μ	36
16,800	460 μ	37
17,400	510 μ	41

Notes:

1. Test conditions:

   speed = 1110 rpm
   run frequency = 18.5 Hz

2. Alarm at 0.002-in. displacement, 0-20 Hz
   Trip at 0.005-in. displacement, 0-20 Hz
3. VE-08Y is vertical orientation accelerometer.
4. Amplitude data are for run frequency vibration.

TABLE 13

PUMP TANK VIBRATION DATA (VE-07Z)
950°F R5 SPEED SCAN

Speed (rpm)	Run Frequency (Hz)	Slip Frequency (Hz)	Background	
			Amplitude (g, rms)	Displacement p-p (μ in.)
700	11.66	25.0	0.0039	786
800	13.33	20.0	0.0045	694
900	15.0	15.0	0.005	609
1000	16.66	10.0	0.0051	503
1050	17.5	7.5	0.0051	456
1110	18.5	4.5	0.0051	408

Notes:

1. VE-072 is radial tank accelerometer (Endevco).
2. Maximum allowable displacement is 0.010 in. p-p at 0-20 Hz.
3. Amplitude data are for run frequency vibration.

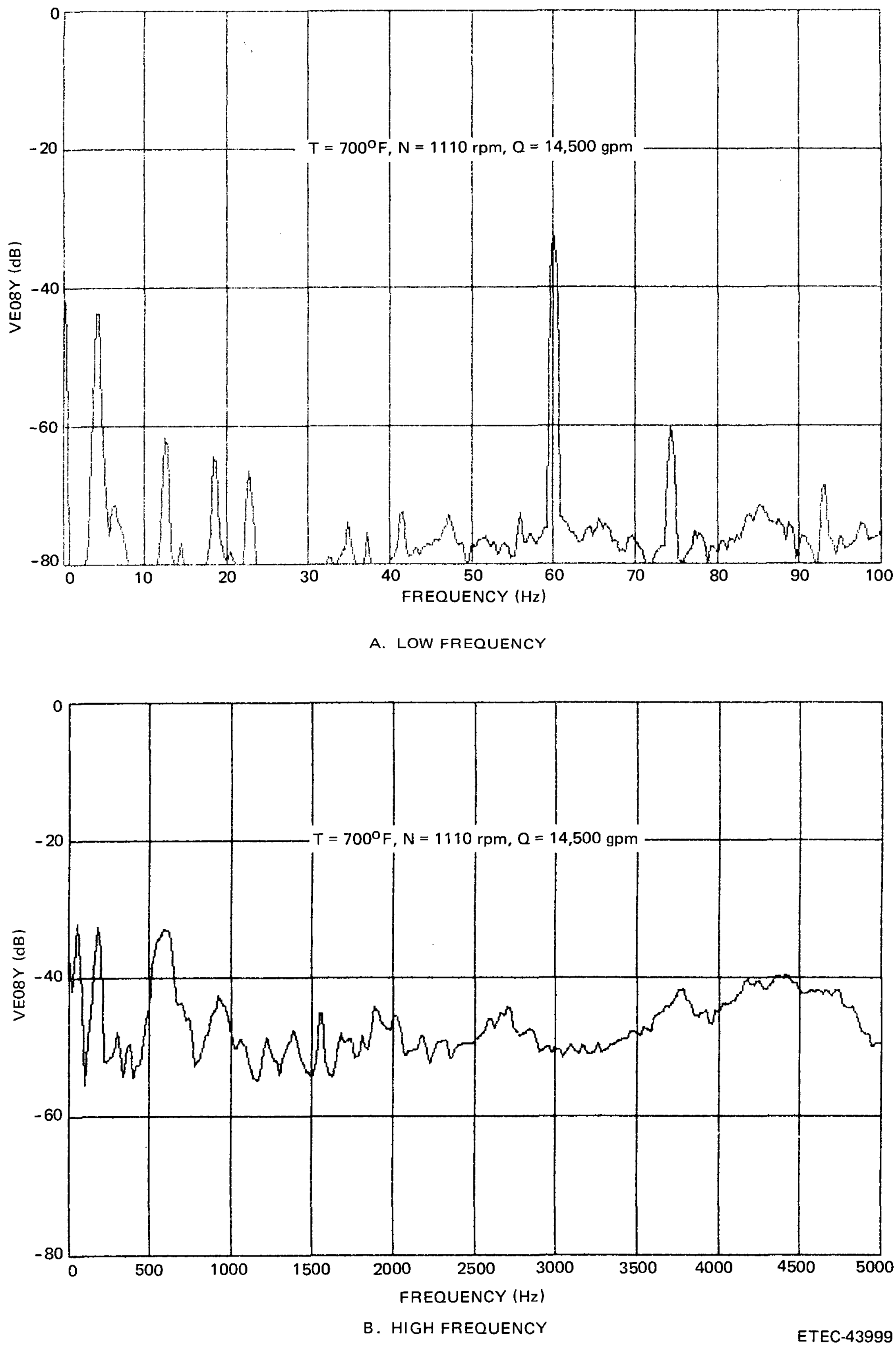


Figure 55. Typical Bearing Seal Housing Vibration Data Plots

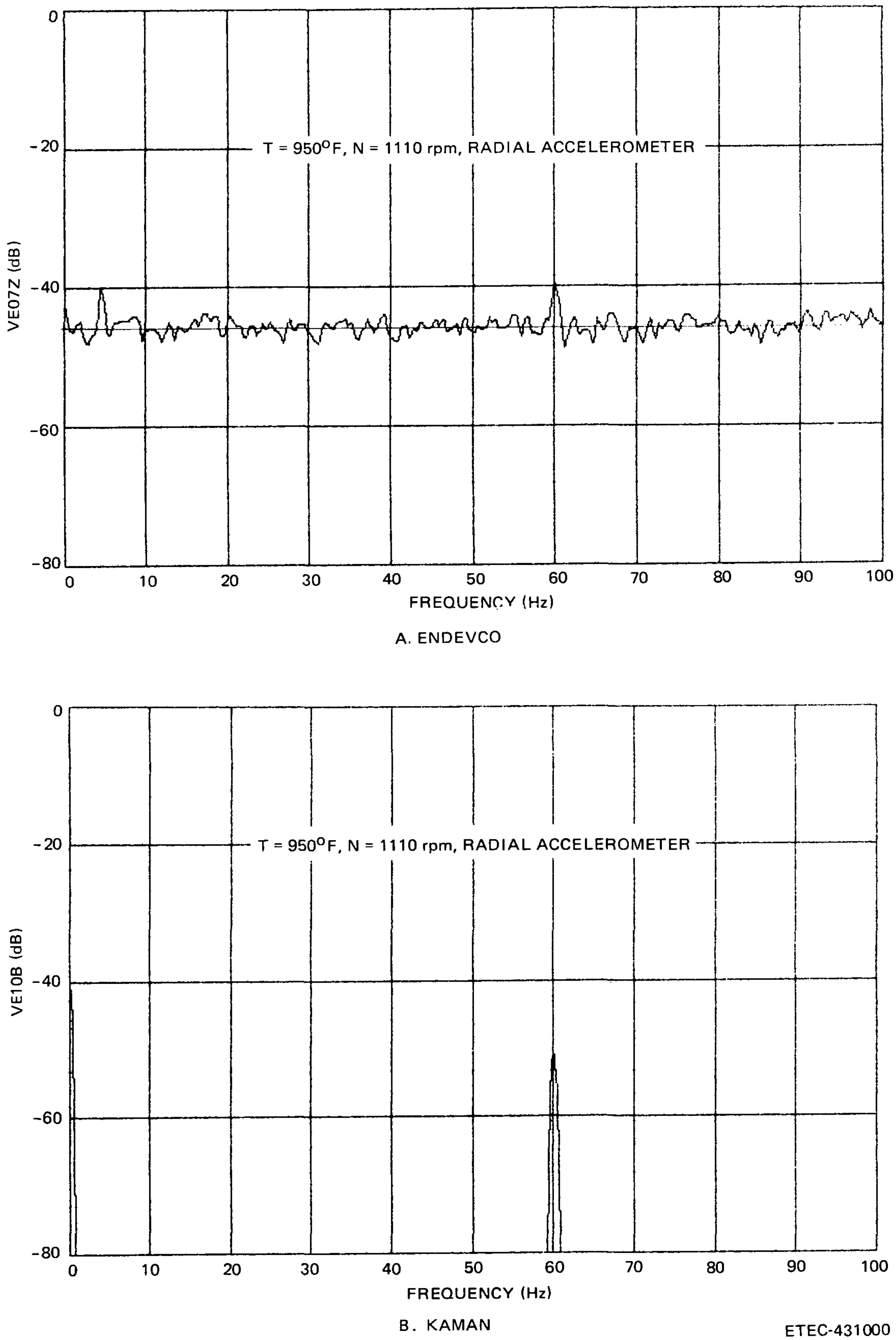


Figure 56. Typical Low-Frequency Pump Tank Vibration Data Plots

Two Kaman Sciences low-frequency accelerometers were also mounted on the pump tank. The sensitivity of these accelerometers was below the threshold value of the spectrum analyzer. A typical Kaman Sciences accelerometer output plot is shown in Figure 56b.

I. BEARING FILM THICKNESS

Eight proximity probes were installed in bearing pockets for the purpose of measuring the pump shaft position relative to the bearing journal. A complete description of the proximity probes' instrumentation system is presented in the Instrumentation section. A description of the calculation techniques is presented in Appendix C.

The bearing orbits were automatically monitored and displayed on CRTs during the tests. The 75% orbit limit and the computed shaft orbits were displayed on the CRTs to allow visual monitoring.

The bearing orbit proximity probes provided bearing orbit data until the pump tank vacuum test was performed in preparation for the cavitation test. Failure of the bearing proximity probes began to occur during the pump tank vacuum checkout test. The vacuum checkout test was performed to verify satisfactory operation of the vacuum pump before the cavitation test. All bearing proximity probes had failed by the end of the cavitation test.

Bearing proximity probe data for a speed calibration run are presented in Figure 57. Shaft speed vs time is plotted in Figure 57a. Bearing proximity probe output for the north and west probes is shown in Figures 57b and 57c. Using zero mils as shaft center, it can be seen from Figure 57b that the proximity probe shows a maximum shaft displacement of 4.1 mils (0.0104 cm) from orbit center in the north-south plane. This corresponds to a bearing film thickness of 6.9 mils (0.0175 cm) in the north-south probe plane. Figure 57c shows the proximity probe output for the west probe. Again, using zero mils as the shaft center, it can be seen from Figure 57c that the maximum shaft displacement in the west-east plane is 1.5 mils (0.0038 cm). This corresponds to a film thickness of 9.5 mils (0.024 cm).

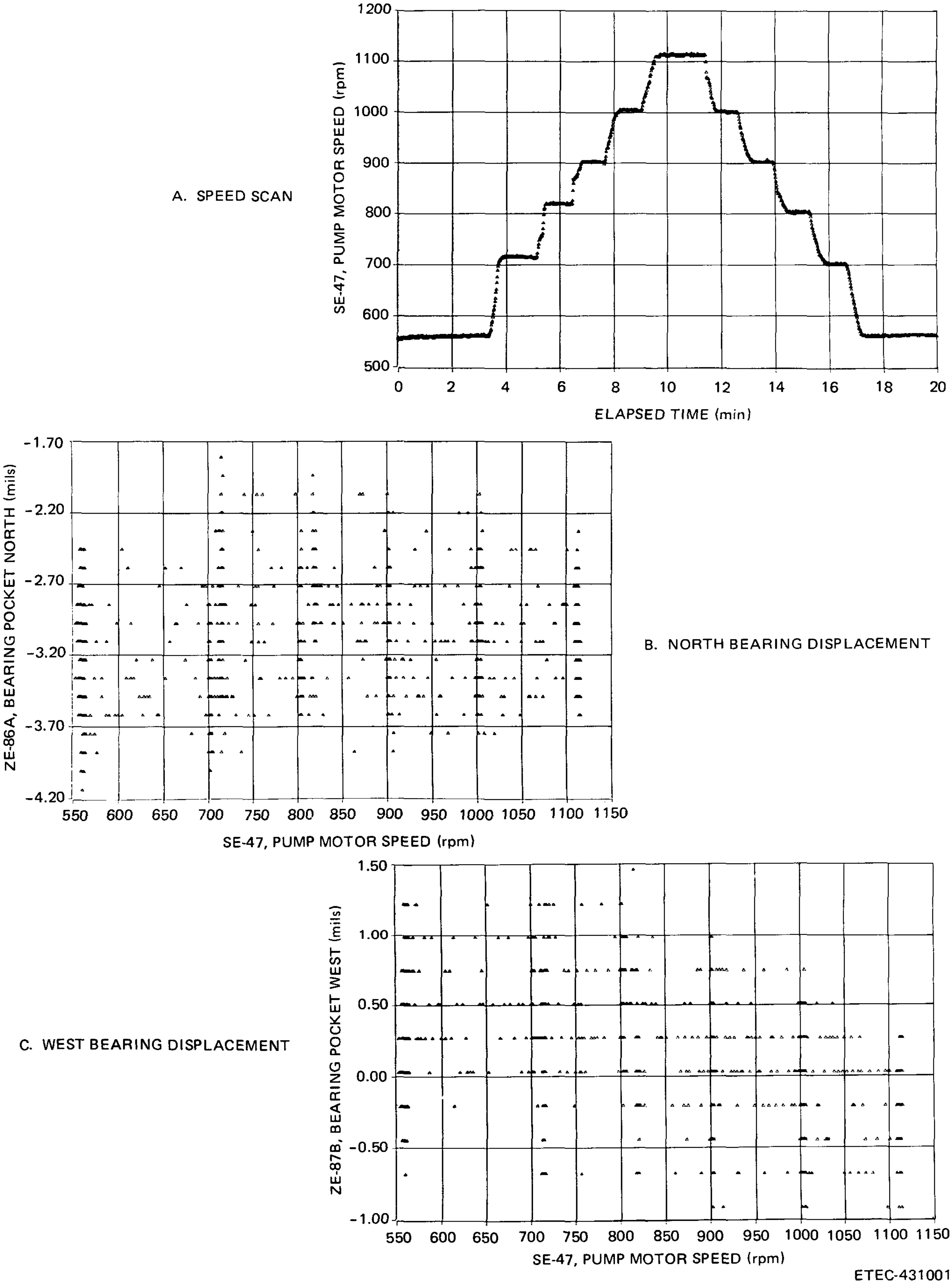


Figure 57. Bearing Displacement Characteristics

Note that in Figure 57c the probe output range is from -1.0 to +1.5 mils (0.0025 cm to 0.0038 cm). The significance is that the shaft orbit is well positioned around the bearing center in the west-east plane. Note also from Figures 57b and 57c that the shaft orbit (as represented by probe output) does not change appreciably with pump speed. The indications from these two figures are that the orbit size may even decrease somewhat at 1110 rpm.

Typical bearing orbit diameter, orbit offset, and bearing film thickness data are presented in Tables 14 and 15. The data presented in these two tables are for 700^{o}F R4 and R5 speed scans, respectively. The data presented show that the film thickness was generally in the range of 7 to 10 mils. The alarm was set to activate if the film thickness decreased to less than 2.75 mils.

Although there was no means of monitoring the bearing orbit after failure of the bearing proximity probes, no evidence was found to indicate that the shaft orbit exceeded the 75% limit.

TABLE 14

TYPICAL BEARING ORBIT DATA, R4
700°F R4 SPEED SCAN 1
JUNE 16-21, 1981

Pump Speed (rpm)	Proximity Probe Set 2			Proximity Probe Set 3		
	Orbit Diameter (mils)	Orbit Offset (mils)	Film Thickness (mils)	Orbit Diameter (mils)	Orbit Offset (mils)	Film Thickness (mils)
555	1.05	3.68	6.79	1.32	0.66	9.68
600	1.97	4.48	5.53	4.20	0.17	8.74
700	2.09	3.83	6.12	3.95	0.35	8.68
800	2.27	4.42	5.45	4.19	1.33	7.57
900	2.10	4.19	5.75	4.19	1.28	7.62
950	2.34	4.26	5.57	4.19	0.57	8.33
1000	2.45	4.70	5.07	3.83	1.05	8.03
1050	1.30	3.77	6.58	1.32	0.73	9.61
1075	1.05	3.86	6.61	1.32	0.86	9.48
1110	1.30	3.85	6.50	1.68	1.00	9.17

TABLE 15

TYPICAL BEARING ORBIT DATA, R5
700°F R5 SPEED SCAN
JUNE 19-20, 1981

Pump Speed (rpm)	Proximity Probe Set 2			Proximity Probe Set 3		
	Orbit Diameter (mils)	Orbit Offset (mils)	Film Thickness (mils)	Orbit Diameter (mils)	Orbit Offset (mils)	Film Thickness (mils)
525	1.61	3.87	6.32	1.91	1.37	8.67
600	1.36	3.90	6.41	1.68	0.89	9.27
700	1.86	3.74	6.33	1.91	0.93	9.11
800	1.30	3.32	7.03	1.44	0.17	10.11
900	1.86	3.54	6.53	2.27	0.37	9.50
950	1.80	3.69	6.41	2.27	0.37	9.50
1000	1.67	3.77	6.40	1.91	0.46	9.59
1025	1.43	3.34	6.95	1.67	0.94	9.22
1050	1.42	3.41	6.88	1.56	0.86	9.36
1075	1.49	3.89	6.36	1.56	0.86	9.36
1110	1.43	3.59	6.70	1.67	0.94	9.22

REFERENCES

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2. OMM-051-00-005, Addendum A, "Intermediate-Size Inducer Pump (ISIP-II) Model 266"

3. N266ER000-002, "Hydrodynamic Design Report," ESG, April 2, 1979

4. P-061E-BQ1-AT022, "Acceptance Test Procedure Index and Summaries, SPTF Stand 1 Quick Turnaround"

5. LMEC-77-4, "FFTF Prototype Pump Testing in SPTF, Final Report," October 15, 1977

6. N266RFT000003, "Minimum Test Series for the Intermediate-Size Inducer Pump in SPTF at ETEC (ISIP-II), Rev. A," December 16, 1980

7. Letter CT/CM-C-4473-020, D. James, Argonne National Laboratory, to L. W. Wheeler, Contract Administrator, Energy Systems Group, "Contract No. 31-109-38-4433, Intermediate-Sized Pump Test (ISIP-II) — Proposed Revisions to the Test Request"

8. 7728-GD1343111, "SPTF Intermediate-Size Inducer Pump-II, Test Procedures Index and Abstracts," January 27, 1981

9. 81ESG-5740 dated June 30, 1981, "Intermediate-Size Inducer Pump (ISIP-II) Modification for NPSH Test Requirements"

10. WDTRS 25-14, Rev. 17, page D-5

11. HEDL Letter 8151831 dated June 11, 1981, "Operation of the Lube Oil Skid with the Aurora Turbine Pump H05 and the Original Fan During the ISIP Program," ETEC-DRF-2403

12. 81ETEC-DRF-3161, dated August 10, 1981, "Transmittal of FFTF Pump Lube Oil Skid Data"

13. "Dynamics Test Handbook," Endevco Corporation, page 17

14. Westinghouse Drawing 114E 809

APPENDIX A

LIST OF SPTF PHOTOGRAPHS

APPENDIX A
LIST OF SPTF PHOTOGRAPHS

Several photographs of the facility and the test article were presented in the body of this report where they were deemed to be of special interest or useful to understanding the text. A list of official ETEC photographs taken during the test program is presented in Table A-1. Some of the photographs listed are near-duplicates of those presented herein and, therefore, are not presented in the text.

TABLE A-1
ETEC PHOTOGRAPHS TAKEN DURING ISIP-II TEST PROGRAM

Date	ETEC No.	Description of Photo
12-08-80	36227CN through 36231CN	Several test article components
01-07-81	362334CN through 362344CN	Pump shaft assembly turnover
01-09-81	36246CN through 36254CN	Assembly of shield plug support cylinder to pump shaft assembly
02-18-81	331094CN through 331105CN	Pump internals lift and transfer from CHCF to SPTF
05-01-81	331107CN through 331113CN	SPTF control room and data acquisition system room
09-23-81	43943CN through 43947CN	Condition of pump shaft after removal of upper bearing assembly

APPENDIX B

CALCULATION OF INITIAL FLOW FOR CAVITATION PERFORMANCE TEST

APPENDIX B

CALCULATION OF INITIAL FLOW FOR CAVITATION PERFORMANCE TEST

I. OBJECT

Calculate the initial flow setting to be used for the cavitation performance test such that when the 3% head drop limit is reached, the flow rate will be 14,500 gpm.

II. PROCEDURE

The procedure described herein is a graphical solution. Equivalent analytical steps may be used if convenient. For plotting the curves, it is recommended that head be plotted on a scale of approximately 5 ft per 1/2 in. (or 5 ft per cm) and that flow be plotted on a scale of approximately 100 gpm per 1/2 in. (or 100 gpm per cm), using graph paper.*

Step 1 — Using test results from the 950°F pretest flow scan, plot the head-flow points, corrected to 1110 rpm, for the test data taken at nominal 13,800 gpm, 14,500 gpm, 15,200 gpm, and 15,900 gpm. Then draw a smooth curve through the test points (identified by a closed circle in Figure B-1).

Note: If instrument recalibration was performed previous to the test, use the test data that was rerun after calibration.

Step 2 — Using 97% of the head values used to plot the test curve in Step 1 and the same values, plot a second head-vs-flow curve (identified by an open circle in Figure B-1).

Step 3 — Record the head value, Ha, where the 97% curve crosses the 14,500-gpm flow line, identified by a diamond in the 97% curve of Figure B-1.

*Use 10 x 10 to the 1/2 in. (or 10 x 10 to the cm) graph paper.

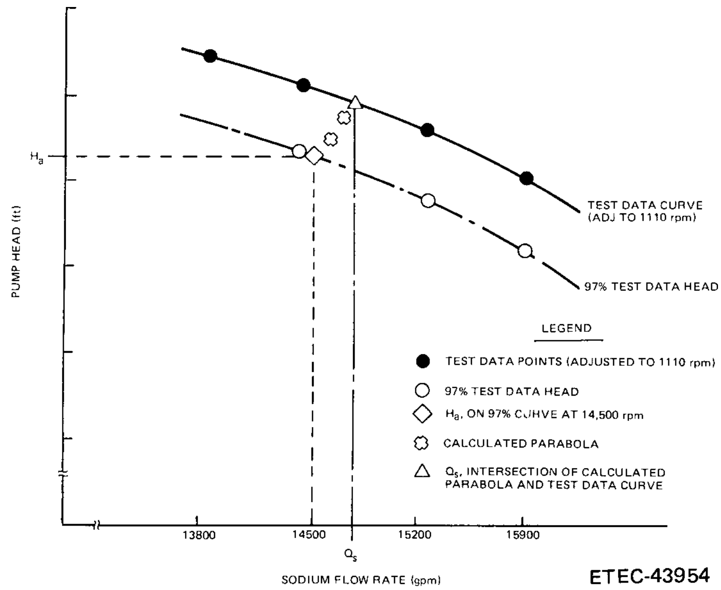


Figure B-1. Graphical Method for Determining Cavitation Initial Flow Rate

Step 4 — Using the value Ha, calculate points for the parabola

$$H = Ha \left(\frac{Q}{14500}\right)^2$$

for values of Q above 14,500 gpm.

Step 5 — Plot the calculated points from Step 4 and draw the segment of the parabola that intersects the test data curve and the 97% curve (identified by "X" on curve of Figure B-1).

Step 6 — Record the flow value, Q_S (identified by a triangle), where the parabola intersects the test head/flow curve in Figure B-1.

Step 7 — Calculate the flow/speed ratio

$$\left(\frac{Q}{N}\right)_S = Q_S/1110$$

This is the flow/speed ratio that should be used to set the MFL butterfly valves in SPTF for the initial test point. At 1110 rpm, the ratio results in a flow rate equal to Q_s.

$$Q_s = (1110) \left(\frac{Q}{N}\right)_s$$

APPENDIX C
PUMP PERFORMANCE EQUATIONS AND SOURCE PROGRAM LISTINGS

APPENDIX C

PUMP PERFORMANCE EQUATIONS AND SOURCE PROGRAM LISTINGS

The equations developed to calculate pump hydraulic performance, pump bearing performance, and a quantitative evaluation of pump tank temperature distribution are presented in this appendix. The source listings of the Fortran programs generated from these equations are also presented.

Information shown on the data printouts and used in the calculations was recorded on magnetic tape to provide storage of the original material for posttest recall.

A. ISIP PUMP PERFORMANCE PROGRAM

1. ISIP-II Pump Requirements for Performance Summary Calculations

The ISIP program is designed to compute and print out selected hydraulic performance parameters when the pump is operating under steady-state conditions and to provide tare information on instrument readouts when the pump is not operating.

2. Data

All performance parameters listed in Table C-1 were sampled 50 times per second for all tests up to July 7, 1981 (after completion of the cavitation test). The sample rate was then changed to 200 samples per second to ensure that average steady-state values were recorded for subsequent tests.

TABLE C-1

ISIP-II PERFORMANCE PARAMETERS

TE-119	Sodium outlet temperature	^{o}F
TE-120	Sodium inlet temperature	^{o}F
SE-20	Pump speed, based on Anadex output	rpm
SE-47	Pump speed, based on tachometer-generator output	rpm
FT-101A	Venturi flowmeter pressure difference (low range)	in. water
FT-101B	Venturi flowmeter pressure difference (high range)	in. water
*FT-101AM	Venturi flowmeter flow rate (low range)	gpm
*FT-101BM	Venturi flowmeter flow rate (high range)	gpm
LT-40	Sodium level above N5 nozzle based on induction probe	in. Na
LT-42	Sodium level above N5 nozzle based on pressure difference	in. Na
PDT-26	Differential pressure across pump	in. water
PT-105	Pump discharge pressure at discharge pressure tap	psig
PT-111	Pump suction pressure at suction pressure tap	psia
PT-113	Pump cover gas pressure	psia
JE-75B	Main motor electrical power input	kW
IE-72	Pony motor current	A

*These values were not recorded on tape, since they are derived.

Although some of the above measurements are not used in the hydraulic performance calculations, they were recorded on magnetic tape for possible future data reduction or recall. Values recorded on magnetic tape were unscaled. The tape included current scaling factor information so that performance data could be computed off-line.

3. Constants

The following constants were used in the calculation equations.

a. Properties

K_1 = 62.4	Specific weight of standard water	lb/ft^3
K_2 = 0.00015	Roughness of discharge pipe	ft
K_3 = 56.34	Specific weight of sodium of 400^oF	lb/ft^3

b. Elevations

ELV1 = 15.04	Elevation of impeller discharge centerline above discharge pressure tap (PT-105)	ft
ELV2 = 5.28	Elevation of impeller discharge centerline above suction nozzle centerline	ft

c. Pipe Diameters

D_1 = 23.5	Inside diameter of pump inlet nozzle	in.
D_2 = 15.25	Inside diameter of pump outlet nozzle	in.
D_1/D_2 = 1.787	Ratio of inlet to outlet pipe diameter	

d. Pipe Length

XLD1 = 2.96	L/D ratio for straight pipe between pump discharge nozzle and discharge pressure tap (PT-105)

e. Pressure

PBAR = 13.8	Standard barometric pressure at SPTF	psia

4. Performance Calculations

Equations marked Δ are intermediate equations, shown because they contain familiar values or forms that have conventionally been used in pump performance calculations. Although not used for actual calculation, they will be shown as comments in the program listing.

a. Symbols

EFF = overall efficiency of pump (%)
EKW = (JE-75B) electrical power input to main motor (kW)
f = fluid friction factor in discharge pipe (dimensionless)
H = head (ft)
N = pump speed (rpm), except N_s = operating specific speed (gpm units)
P = pressure (psi)
Q = flow rate (gpm)
RE = Reynolds number (dimensionless)
S = suction specific speed (gpm units)
T = absolute temperature (^{o}K)
t = Fahrenheit temperature (^{o}F)
V = velocity (ft/sec)
Z = vertical distance (ft)
ρ = specific weight (lb/ft^3)
σ = specific gravity referred to standard water (dimensionless)
μ = absolute viscosity (lb•mass/ft•s)

b. Subscripts

1 = pump inlet (suction)
2 = pump outlet (discharge)
} Excepting specifically defined constants
c = speed corrected value
cg = cover gas
f = fluid friction loss

j = variable subscript for "DO LOOP" calculations

s = specific speed

sv = NPSH

t = total

v = velocity

vp = vapor pressure

c. Crossover Logic

Speed Crossover:

If (SE-47) >399, then N = (SE-47).

If (SE-47) $\leq$ 399, then N = 94 (pony motor speed).
This logic is used because SE-47 is not accurate at pony motor speed. Pony motor speed is 94 to 94.5 rpm.

Flow Crossover:

Q = (FT-101BM)

If N <100 and (FT-101B) $\leq$ 250, then Q = (FT-101AM).

Continue with performance calculations.

d. Sodium Properties

Specific weight (ρ) of sodium (lb/ft^3):

$$\rho = 59.566 - 0.00795\,(t) - 2.872 \times 10^{-7}\,(t)^2 + 6.04 \times 10^{-11}\,(t)^3$$

Ref. Sodium-NaK Engineering Handbook, Vol. I; O. J. Foust (1972)

where t = (TE-120)

Specific gravity (σ) of sodium:

$$\sigma = \rho/K_1$$

$$= \rho/62.4$$

Absolute temperature (T) (^oK):

$$T = (t + 459.69)/1.8$$

where $0^o R = -459.69^oF$

$$t = (TE\text{-}120)$$

Sodium viscosity (μ) (lb•mass/ft•s):

If $t \leq 932^oF$,

$$\mu = 6.72 \times 10^{-4} \left[0.1235\sigma^{1/3} \times e^{(697\ \sigma/T)}\right]$$

If $t > 932^oF$,

$$\mu = 6.72 \times 10^{-4} \left[0.0851\sigma^{1/3} \times e^{(1040\ \sigma/T)}\right]$$

Ref. Sodium-NaK Engineering Handbook, Vol. I; O. J. Foust (1972) where 6.72×10^{-4} = lb•mass/ft•s per centipoise

Sodium vapor head (H_{vp}) in ft of sodium liquid (ft)

$$H_{vp} = 2116 \frac{10^{[6.354-(5567/T)-(0.2171 \ln T)]}}{\rho}$$

Ref. same as above; equation modified to yield head

e. Velocities

Inlet velocity (V_1) (ft/s)

Δ $$V_1 = \frac{0.321Q}{0.785\ D_1^2}$$

Outlet velocity (V_2)

Δ $$V_2 = V_1(D_1/D_2)^2$$

f. Velocity heads (ft)

Inlet velocity head (H_{v1})

$$H_{v1} = V_1^2/64.4$$

Outlet velocity head (H_{v2})

$$H_{v2} = V_2^2/64.4$$

g. Reynolds number in outlet pipe

$$RE - \frac{\rho V_2 D_2}{12\mu}$$

h. Outlet pipe friction factor (f)

Δ $$f = 0.0055 \left[1 + \left(\frac{20{,}000\ K_2}{D_2/12} + \frac{10^6}{RE}\right)^{1/3}\right]$$

Δ $$f = 0.0055 \left[1 + \left(2.3607 + \frac{10^6}{RE}\right)^{1/3}\right]$$

i. Fluid friction head loss (H_f) in discharge pipe (ft)

$$H_f = f \times (XLD1) H_{v2}$$

$$= 2.96 \cdot f \cdot H_{v2}$$

j. Total head across pump (H_t) (ft)

If ΔP <250 in. water, then

$$H_t = \frac{\Delta P}{12\sigma} - 0.4 + H_{v2} - H_{v1}$$

where 0.4 = elevation correction for NaK capillary tubes between pressure taps and differential pressure transmitter,

$$\Delta P = (PDT\text{-}26)$$

If $\Delta P > 250$ in. water, then

Sodium level over impeller discharge ℄ (Z) (ft)

If (LT-40) $\geq$115, then Z = [(LT-40) - 26.0]/12.0

If (LT-40) <115, then Z = [(LT-42) - 26.0]/12.0

Cover gas head (H_{cg}) in feet of sodium (ft)

$$H_{cg} = P_{cg} \times 144/\rho$$

where P_{cg} = (PT-113)

Total inlet head (H_1) referred to impeller discharge ℄ (ft)

$$H_1 = H_{cg} + Z + H_{v1}$$

where Z = level above impeller ℄

Total outlet head (H_2) referred to impeller discharge ℄ (ft)

Δ $$H_2 = 144 \frac{(P_2 + PBAR)}{\rho} + H_{v2} + H_f - ELV1$$

$$H_2 = 144 \frac{(P_2 - 13.8)}{\rho} + H_{v2} + H_f - 15.04$$

where P_2 = (PT-105)

Total head (H_2) (ft)

$$H_t = H_2 - H_1$$

k. <u>Net positive suction head (H_{sv})</u>

Δ $$H_{sv} = H_1 + ELV2 - H_{vp}$$

Referred to inlet ℄ (ft)

$$H_{sv} = H_1 + 5.28 - H_{vp}$$

Referred to inducer inlet (ft)

$$H_{svI} = H_{sv} - DIFFI$$

where DIFFI = 3.96 ft
(difference in elevation from inlet ℄ to inducer inlet)

l. Suction specific speed (S) at inlet nozzle

$$S = \frac{NQ^{1/2}}{H_{sv}^{3/4}}$$

m. Operating specific speed (N_s)

$$N_s = \frac{NQ^{1/2}}{H_t^{3/4}}$$

n. Overall efficiency (EFF)

If N $\leq$100, then EFF = $$$$$ (no calculation) (%)
If N >100, then

Δ $$EFF = \frac{0.7457\ H_t Q\sigma}{3960\ EKW} \times 100$$

$$EFF = 0.01883\ \frac{H_t Q\sigma}{EKW}$$

where EKW = (JE-75B) (main motor power, kW)

o. Speed corrected head, flow, and power values (H_{cj}, Q_{cj}, and PWR_{cj})

Corrected speeds (N_{cj}) where $j = 1,2,3,4$

$N_{c1} = 500$

$N_{c2} = 700$

$N_{c3} = 900$

$N_{c4} = 1110$

DØ for j = 1 through j = 4

$$H_{cj} = H_t \left(\frac{N_{cj}}{N}\right)^2$$

$$Q_{cj} = Q \left(\frac{N_{cj}}{N}\right)$$

$$PWR_{cj} = PWR \left(\frac{N_{cj}}{N}\right)^{1.895}$$

Note: Exponent for power extrapolation derived from FFTF test data.

The source program listing for the computer program ISIP is presented as Table C-2.

B. BPERF — BEARING PERFORMANCE PROGRAM

This section presents the ISIP-II pump-bearing performance calculation equations and methods, program BPERF, and Fortran source program listing for bearing performance.

ISIP-II Pump-Bearing Performance

The following equations describe the requirements for digital computer analysis of pump shaft dynamics, as measured by the proximity probes. Output data were included in the printout as part of the steady-state pump performance

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 1 of 10)

```
&ISIP  T=00004 IS ON CR00013 USING 00066 BLKS R=0000

FTN4,L
      PROGRAM ISIP(),    G.A.  SPTF  <810707.1615>
C...........................................................................C
C                                                                           C
C                ISIP      HYDRAULIC PERFORMANCE PROGRAM                    C
C                          REV-790608                                       C
C                                                                           C
C                                                                           C
C                              IF ISSW(2) IS <ON>, PRINTS PART 1,           C
C          REGARDLESS OF FLOW.                                              C
C
C                              IF ISSW(3) IS <ON>, PRINTS ALL VALUES
C          READ PRIOR TO CALCULATIONS.
C                                                                           C
C...........................................................................C
C
C                                          MODIFIED BY   G.ANDERSON  12/13/78
CD                                                                   7/5/79
C
      DIMENSION RK(3),SPC(4),HC(4),QC(4),CJE75(4),
     +     JPRAM(17),ICHNO(28),NCH(3),VOLTS(256) ,IPRAM(5),NSE20(15),
     +     IROW(180),AVG(17),VMAX(17),VMIN(17),STD(17),SC(256)
      COMMON IA(800),RA(400),KDAT(281),ITTL(256,4)
      EQUIVALENCE (TE120 ,AVG( 1)),(SE47  ,AVG( 2)),(FT10AM,AVG( 3))
     &,            (FT10BM,AVG( 4)),(FE108A,AVG( 5)),(RLT40 ,AVG( 6))
     &,            (RLT42 ,AVG( 7)),(PDT26 ,AVG( 8)),(PT105 ,AVG( 9))
     &,            (PT111 ,AVG(10)),(PT113B,AVG(11)),(E75B  ,AVG(12))
     &,            (FT101A,AVG(13)),(FT101B,AVG(14)),(E72   ,AVG(15))
     &,            (SE20  ,AVG(16)),(TE119 ,AVG(17))
C
      DATA DIFII/3.96/
      DATA NSE20/2H S,2HE-,2H20,2H  ,2H  ,2HPU,2HMP,2H S,2HPD,
     +          2H.(,2HRP,2HM),3*2H  /
      DATA  RK / 62.4, 0.00015, 56.34 / , ELV1,ELV2 / 15.04, 5.28 /
      DATA  D1,D2 / 23.50, 15.25 / , XLD1 / 2.96 / , PBAR / 13.8 /
      DATA  SPC / 500., 700., 900., 1110. / , IPRAM /5*0/,LIST/6/,
     +     NSMP/200/
      DATA   IBPFL /0/ , IYES /2HYE/
      DATA  ICHNO /2HSE,2H-4,2H7 ,2H  , 2HSE,2H-4,2H7 ,2H  ,
     +             2HFT,2H10,2H1B,2HM  , 2HFE,2H-1,2H04,2H  ,
     +             2HPT,2H-1,2H05,2H   , 2HPD,2HT-,2H26,2H  ,
     +             2HFT,2H10,2H1A,2HM   /
      DATA  IROW /2H T,2HE-,2H12,2H0 ,2H  ,2HNA,2H T,2HEM,2HP.,2H(F,
     +  2H) ,2H  ,2H  ,2H  ,2H  ,2H S,2HE-,2H47,2H  ,2H  ,2HPU,2HMP,
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 2 of 10)

```
           +  2H S,2HPD,2H.(,2HRP,2HM),2H  ,2H  ,2H  ,2H F,2HT1,2H01,2HAM,
           +  2H  ,2HFL,2HOW,2H L,2HO-,2HRA,2HNG,2HE(,2HGP,2HM),2H  ,2H F,
           +  2HT1,2H01,2HBM,2H  ,2HFL,2HOW,2H H,2HI-,2HRA,2HNG,2HE(,2HGP,
           +  2HM),2H  ,2H F,2HE1,2H08,2HB ,2H  ,2HFL,2HOW,2H P,2HM ,2HMT,
           +  2HR ,2H(G,2HPM,2H) ,2H  ,2H L,2HT-,2H40,2H  ,2H  ,2HLE,2HVE,
           +  2HL ,2H(I,2HN),2H  ,2H  ,2H  ,2H  ,2H  ,2H L,2HT-,2H42,2H  ,
           +  2H  ,2HLE,2HVE,2HL ,2H(I,2HN),2H  ,2H  ,2H  ,2H  ,2H  ,2H P,
           +  2HDT,2H-2,2H6 ,2H  ,2HDE,2HLT,2HA-,2HP ,2H(I,2HN.,2H H,2H20,
           +  2H) ,2H  ,2H P,2HT-,2H10,2H5 ,2H  ,2HDI,2HSC,2HH.,2HPR,2HES,
           +  2H.(,2HPS,2HIG,2H) ,2H  ,2H P,2HT-,2H11,2H1 ,2H  ,2HSU,2HCT,
           +  2H. ,2HFR,2HES,2H.(,2HPS,2HIA,2H) ,2H  ,2H P,2HT-,2H11,2H3B,
           +  2H  ,2HCO,2HV.,2HGA,2HS ,2HPR,2HES,2H.(,2HPS,2HIA,2H) ,2H J,
           +  2HE-,2H75,2HB ,2H  ,2HMA,2HIN,2H M,2HOT,2H.P,2HOW,2HER,2H(K,
           +  2HW),2H  /
      C
            DATA JPRAM/181,145,79,80, 82,144,162, 64,159,175,
           &            178,151,232,158,147,137,180/
      C..........START
            RNSMP = FLOAT(NSMP)
            RNSM1 = RNSMP - 1.0
      C...       CONSTANTS
            D1D2 = D1/D2
            THIRD = 1./3.
            C34   = 3./4.
      C
      C   INITIALIZE BLKOT
      C
            CALL BLKOT(SC,1)
        100 FORMAT(A2)
      C
      C
      C    TAKE THE DATA FOR CALCULATION
      C
      C
      C...       CALL SUBROUTINE  *WAVRG*,   MUX & PROCESS DATA
            CALL WAVRG(NSMP,LIST,AVG,VMAX,VMIN,STD,SC,VOLTS,IDA,IHR,MIN,ISEC,
           +            JPRAM)
      C
            JE75B = IFIX(E75B)
            IE72  = IFIX(E72)
      CJ
            IF(ISSW(3))120,180
        120 DO 160 I=1,17
            J=JPRAM(I)
            WRITE(LIST,140)I,J,(ITTL(J,K),K=1,4),AVG(I)
        140 FORMAT(2X,I2,2X,I3,5X,4A2,5X,F10.4)
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 3 of 10)

```
  160 CONTINUE
CJ
C
C...      HYDRAULIC PERFORMANCE CALCULATIONS
C
C...          SODIUM PROPERTIES
C...          SPECIFIC WEIGHT, RHO-NA
  180 RHONA = 59.566 - (.00795*TE120) - ((2.872*10.**(-7))*(TE120**2))
     &                + ((6.04*10.**(-11))*(TE120**3))
C...          SPECIFIC GRAVITY, SIGMA-NA
      SIGNA = RHONA/RK(1)
C...      COVER GAS HEAD (HCG), IN FEET OF SODIUM
      HCG = PT113B*(144./RHONA)
C
C
C...      SELECT PART I. OR PART II. CALCULATIONS
C
C
      IF(ISSW(2).LT.0)GO TO 560
      IF(SE20.GT.50.0.OR.SE47.GT.50.0) GO TO 200
      GO TO 560
C
C
C
C...       PART I. CALCULATIONS
C
C...       SPEED CROSSOVER
  200 SP = SE47
      NCH(1) = 1
C...       USE PONY MOTOR SPEED
      IF(SP   .GT.399.0) GO TO 220
      SP = 94.0
      NCH(1) = 5
C...       FLOW CROSSOVER
  220 Q = FT10BM
      NCH(2) = 9
      IF(SP.LE.100.0) GO TO 240
C...           SPEED . GT . 100
      IF(FT101B.GT.250.0) GO TO 260
C...       FT101B.LE.250 INCHES, USE FT101AM (LO-RANGE FLOW)
      Q = FT10AM
      NCH(2) = 25
      GO TO 260
C...       SPEED . LE . 100
  240 IF(FT10AM.GT.2200.0) GO TO 260
C...        FT101AM . LE . 2200, USE FE108A
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 4 of 10)

```
      Q = FE108A
      Q=FT10AM
      NCH(2) = 13
C...        SODIUM PROPERTIES
C...        ABSOLUTE TEMPERATURE
  260 TABS = (TE120+459.67)/1.8
C...        SODIUM VISCOSITY, MU-NA
      CONS1 = 0.1235
      CONS2 = 697.0
      IF(TE120.LE.932.0) GO TO 280
      CONS1 = 0.0851
      CONS2 = 1040.
  280 RMUNA = (6.72*10.**(-4))*((CONS1*SIGNA**THIRD)*EXP((CONS2*SIGNA)
     &          /TABS))
C...         SODIUM VAPOR HEAD,  HVP
      IF(TABS.GT.0.0) GO TO 320
      WRITE( 1  ,300) TABS
  300 FORMAT(/"  NEGATIVE OR ZERO *TABS* VALUE ",F9.4,
     &          ", ILLEGAL  ALOG  ARGUMENT."/)
      STOP  10
  320 HVP = 2116.*(10.**(6.354-(5567./TABS)-(.2171*ALOG(TABS)))/RHONA)
C...       INLET VELOCITY,  V1
C...       V1 = (0.321*Q)/(0.785*D1**2)
      V1 = Q*7.4E-4
C...       OUTLET VELOCITY,  V2
      V2 = V1*(D1D2**2)
C...       VELOCITY HEAD, INLET VELOCITY: HV1 & HV2
      HV1 = (V1**2)/64.4
      HV2 = (V2**2)/64.4
C...       REYNOLDS NUMBER (RE) IN OUTLET PIPE
      RE = (RHONA*V2*D2)/(12.*RMUNA)
C...       OUTLET PIPE FRICTION FACTOR,  F
      F = 0.0055*(1.+(2.3607+((10.**6)/RE))**THIRD)
C...       FLUID FRICTION HEAD LOSS (HF) IN DISCHARGE PIPE
      HF = F * XLD1 * HV2
C...       SODIUM LEVEL OVER IMPELLER DISCHARGE CENTER-LINE:  Z
  340 Z = (RLT40-26.0)/12.0
      IF(RLT40.LT.115.0) Z = (RLT42-26.0)/12.0
C...       (COVER GAS HEAD (HCG) ALREADY CALCULATED)
C...      TOTAL INLET HEAD (H1) REFERRED TO IMPELLER DISCHARGE CENTER-LINE
      H1 = HCG + Z + HV1
C...      TOTAL OUTLET HEAD (H2) REFERRED TO IMPELLER DISCHARGE CENTER-LINE
      ZINCH = Z*12.0
      H2 = 144.*((PT105+PBAR)/RHONA) + HV2 + HF - ELV1
C
C...       CALCULATE TOTAL HEAD,  HT
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 5 of 10)

```
C
        IF(PDT26.GT.9.0 .OR. PT105.GE.18.0) GO TO 360
        HT = (PDT26*144/RHONA) - 0.4 + (HV2-HV1)
        NCH(3) = 21
        GO TO 380
C...      TOTAL HEAD ( DELTA-P  >>  250 )
  360 HT = H2 - H1
        NCH(3) = 17
C...    NET POSITIVE SUCTION HEAD (HSV) REFERRED TO INLET CENTER-LINE
  380 HSV = H1 + ELV2 - HVP
C
C  NPSH REFERENCED TO INDUCER INLET
C
        HSVI=HSV-DIFII
C...    SUCTION SPECIFIC SPEED (S) AT INLET NOZZLE
        S = (SP*SQRT(Q))/(HSV**C34)
C...    OPERATING SPECIFIC SPEED  (ONS)
        ONS = (SP*SQRT(Q))/(HT**C34)
C...    OVERALL  EFFICIENCY:  EFF
        EFF = 0.0
        IF(SP.GT.100.0) EFF = 0.01883*((HT*Q*SIGNA)/E75B)
C
C  CALCULATE Q/N AND H/N**2,SKW
C
        QN=Q/SP
        HN2=HT/(SP**2)
        SKW=(.00285*SP**1.895)
       +   *(RHONA*(1+.98E-5*(TE120-70.0))/51.46)
       +   *(.2987*ALOG(Q*1110./SP)-1.8658)
        PR=E75B/SKW *100.
C
C...      SPEED-CORRECTED HEAD & FLOW VALUES
        DO 400 J=1,4
        HC(J) = HT*((SPC(J)/SP)**2)
        CJE75(J)=E75B*((SPC(J)/SP)**1.895)*51.806/RHONA
  400 QC(J) =  Q*(SPC(J)/SP)
C
C...      WRITE  PART I.  OUTPUT,  "C"-FORMAT.
C
C...          (METRIC CONVERSIONS, ETC.)
        ITE12 = IFIX(TE120)
        CTE12 = (TE120-32.0)/1.8
        NQ    = IFIX(Q)
        QM    = (Q * 0.0037815)/60.
        HTM   = HT * 0.3048
        HSVM  = HSV * 0.3048
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 6 of 10)

```
            HSVIM=HSVI*.3048
            PDT2M = PDT26 * 0.02540
            IHCGM = IFIX(HCG * 6895.0)
            PT13M = PT113B*6894.757
            ONSM = ONS*(771.31/1259.79)
            SM  =  S*(771.31/1259.79)
            ZM = ZINCH/39.37
      C...
            WRITE(LIST,440)IDA,IHR,MIN,ISEC
        440 FORMAT(1H1,
           &  " STEADY-STATE PUMP PERFORMANCE -- ISIP PRINTOUT", 5X,
           & "DATE: ("I3")",I4":"I2":"I2)
            CALL INSRT(LIST)
            WRITE(LIST,460)
        460 FORMAT(
           +      42X,"APPROVAL:"//
           +        42X,"DATE     :"," OPERATOR COMMENT:")
      C...      OPERATOR COMMENT
      C...
            WRITE(LIST,480)
        480 FORMAT(/" HYDRAULIC PERFORMANCE:",23X,"METRIC UNITS"/)
            WRITE(LIST,500) ITE12,CTE12,SP,(ICHNO(I),I=NCH(1),NCH(1)+3),
           +        NQ,(ICHNO(I),I=NCH(2),NCH(2)+3),   QM,   HT,
           +        (ICHNO(I),I=NCH(3),NCH(3)+3),HTM,HSV,HSVM,HSVI,HSVIM,QN,HN2
        500 FORMAT(5X,"TEMP:",2X,I5," F",31X,"TEMP:",2X,F6.1," C"/5X,"SPEED:",
           +         X,F6.1," RPM",5X,"CHANNEL ",4A2/5X,"FLOW:",2X,I6," GPM",5X,
           +         "CHANNEL ",4A2,7X,"FLOW: ",F7.3," CU.M/SEC"/5X,"HEAD:",
           +         2X,F6.1," FT.",5X,"CHANNEL ",4A2,7X,"HEAD: ",F7.2," M"/5X,
           +"NPSH:" 2X,F6.1," FT."5X"INLET NOZZLE  C.L."5X,"NPSH: ",F7.2,
           +" M"/,5X,
           +"NPSH:" 2X,F6.1," FT."5X"INDUCER INLET REF."5X,"NPSH: ",F7.2,
           +" M"/,
           +     5X "Q/N :"F8.3" GAL/REV"/,
           +     5X "H/N**2:"E9.5/ )
            WRITE(LIST,520) ZINCH,ZM,PT113B,PT13M,JE758,E72,EFF,
           &                     S,SM,ONS,ONSM
        520 FORMAT(5X,"LEVEL OVER IMP.:",4X,I4," IN.",17X,"LEVEL: ",F6.2,
           +        " M"/5X,"COVER GAS PRESSURE: ",F7.2," PSIA",13X,"PRES.: ",
           +     F6.0," PAA"/5X,"ELEC. POWER: ",I6," KW",5X,"PONY MOTOR CUR. "
           +        ,F5.1," AMPS"/5X,"EFFICIENCY:",3X,F5.1," PERCENT"/5X,
           +        "SUCT. SP. SPEED: ",F6.0,12X,"SUCT. SP. SPEED: ",F6.0/5X,
           +        "OPER. SP. SPEED: ",F6.0,12X,"OPER. SP. SPEED: ",F6.0/)
            WRITE(LIST,540) (QC(J),J=1,4),(HC(J),J=1,4),CJE75
        540 FORMAT(7X,"CORRECTED VALUES:",8X,"500 RPM",4X,"700 RPM",3X,
           +        "900 RPM",3X,"1110 RPM"//10X,"FLOW (GPM):",11X,I6,5X,I6,
           +        4X,I6,4X,I6/10X,"HEAD (FT.):",10X,F7.1,4X,F7.1,3X,F7.1,
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 7 of 10)

```
     +      3X,F7.1,/,10X"POWER(KW)(950F) :",4X,F7.1,4X,F7.1,3X,F7.1,3X,
     +        F7.1)
C
C      GO TO 680
C
C
C
C
C
C
C
C
C    BPERF OUTPUT HERE
C
       CALL EXEC(9,6HBPERF    )
C
C...        PART  II.  CALCULATIONS FOR ZERO CHECK OUTPUT
C
C...   (SODIUM SPEC. WT. & SPEC. GRAVITY ALREADY CALCULATED)
C...        CALCULATE LOW-RANGE HEAD  (HA)
  560 HA = (PDT26*144./RHONA) - 0.4
C...        CALCULATE HI-RANGE HEAD  (HB)
C...       (COVER GAS HEAD (HCG) ALREADY CALCULATED)
C...        SODIUM LEVEL OVER IMPELLER DISCHARGE CENTER-LINE:  Z
       CONST = RLT40
       IF(RLT40.LT.115.0) CONST = RLT42
       Z = (CONST-26.0)/12.0
       HB = 144.*((PT105+13.8)/RHONA) - HCG - Z - ELV1
C
C...         WRITE  PART II.  OUTPUT,  "D"-FORMAT
C
       WRITE(LIST,580)IDA,IHR,MIN,ISEC
  580 FORMAT(
     &  "1INSTRUMENT ZERO CHECK FOR ISIP PROGRAM" 5X,
     +  "DATE: ("I3")"I4":"I2":"I2,/)
       CALL INSRT(LIST)
       WRITE(LIST,460)
C...         OPERATOR COMMENT
       WRITE(LIST,600) HA,HB
  600 FORMAT(/" PUMP HEAD: LOW RANGE  ",F6.1," FT."/12X,"HIGH RANGE ",
     &        F6.1," FT."/33X,"AVG.",5X,"MAX.",5X,"MIN.",3X,"STD.DEV."/)
C...     MEAN, MAX, MIN, & STD. DEVIATION
       DO 620 LL=1,12
       LR = 15*LL - 14
  620 WRITE(LIST,640) (IROW(IR),IR=LR,LR+14),AVG(LL),VMAX(LL),
     &                  VMIN(LL),STD(LL)
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 8 of 10)

```
          WRITE(LIST,640)NSE20,AVG(16),
         +  VMAX(16),VMIN(16),STD(16)
      640 FORMAT(15A2,X,F6.1,3(3X,F6.1))
          WRITE(LIST,645)PR
C 645     FORMAT(/" PERCENT SKW = "F5.1)
C...          OPTIONAL SCHEDULING OF *BPERF*, BEARING PERFORMANCE PGM.
C...
          END
          SUBROUTINE WAVRG(LOOPS,IOUT,RMEAN,RHIGH,RLOW,RSIGM,SC,VOLTS,
         +                    IDA,IHR,MIN,ISEC,LPRAM)
C.......................................................................C
C                                                   VERSION:   77,0118  C
C                                                                       C
C          "AVRYG" ROUTINE FOR ISIP PROGRAM (ISIP )              C
C                                                                       C
C                                                                       C
C          ITYPE = RECORD TYPE OF READINGS USED IN CALCULATIONS         C
C          NPAR  = # OF PARAMETERS AVERAGED = 17                        C
C          NSKIP = # OF MUX READINGS NOT RECORDED OR USED IN CALCULATIONS C
C          LOOPS = # OF MUX READINGS USED IN CALCULATIONS               C
C                                                                       C
C.......................................................................C
          DIMENSION  LPRAM( 1),RMEAN(17),
         &      RLOW(17),RHIGH(17),RSIGM(17)
         &     ,SC( 1 ),ITIME(5),VOLTS(1)
          COMMON IA(800),RA(400),KDAT(281),ITTL(256,4)
          DATA  NPAR,IMAG,ITYPE,NSKIP /17,8,4,2/
C
C...       PARAMETER DATA IS STORED IN THE FOLLOWING ORDER:
C
C         LPRAM#      I.D.     SEQ.#        NEW SEQ#
C
C           1       TE-120      183          181
C           2       SE-47       176          145
C           3       FT101AM     108           79
C           4       FT101BM     109           80
C           5       FT104B      115           82
C           6       LT-40       101          144
C           7       LT-42       102          162
C           8       PDT-26      131          142
C           9       PT-105      132          159
C          10       PT-111      129          175
C          11       PT-113B     137          178
C          12       JE-75B      163          151
C          13       FT-101A     110          232
C          14       FT-101B     111          158
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 9 of 10)

```
C         15      TE-72        162          147
C         16      SE-20        175          137
C         17      TE-119       182          180
C
C   PARAMETERS 1-12 MUST BE IN ABOVE ORDER FOR USE BY PGM.  * ISIP*
C
C...      INITIALIZE, BRING IN COEFFICIENTS FROM RA
C
C   INITIALIZE
        DO 100 I=1,NPAR
        RLOW(I)=999999.
        RHIGH(I)=-999999.
        RSIGM(I)=0.0
    100 RMEAN(I)=0.0
C
        DO 120 I=1,NSKIP
        CALL EXEC(9,6HMUX    )
    120 CONTINUE
        CALL RDCLK(IDA,IHR,MIN,ISEC,MSEC)
    140 DO 180 I=1,LOOPS
        CALL EXEC (9,6HMUX    )
        CALL SCAL(2,NT,IOUT,KDAT,SC,VOLTS,1)
        DO 160 J=1,NPAR
        VAL=SC(LPRAM(J))
        RMEAN(J)=RMEAN(J)+VAL
        RSIGM(J)=RSIGM(J)+VAL**2
        IF(VAL.GT.RHIGH(J)) RHIGH(J)=VAL
        IF(VAL.LT.RLOW(J)) RLOW(J)=VAL
    160 CONTINUE
    180 CONTINUE
        DO 200 J=1,NPAR
        RSIGM(J)=(LOOPS*RSIGM(J)-(RMEAN(J)**2))/(LOOPS*(LOOPS-1))
        RSIGM(J)=SQRT(ABS(RSIGM(J)))
    200 RMEAN(J)=RMEAN(J)/LOOPS
        CALL EXEC(11,ITIME,IYEAR)
        CALL DATE(ITIME(5),MONTH,IYEAR)
C
C
        IF(ISSW(10).LT.0)WRITE(IOUT,220)
    220 FORMAT(1H1/15X" SCALED MEANS,HIGHS, LOWS OF MEASUREMENTS")
        IF(ISSW(10).LT.0)WRITE(IOUT,240)
    240 FORMAT(" SEQ"5X"PARAMETER"7X"MEAN",
      &                 9X"LOWEST"4X"HIGHEST",6X,"MUX"/)
        DO 280 I=1,NPAR
        J=LPRAM(I)
        IF(ISSW(10).LT.0)WRITE(IOUT,260) J,(ITTL(J,K),K=1,4),RMEAN(I),
```

TABLE C-2

ISIP SOURCE PROGRAM LISTING
(Sheet 10 of 10)

```
     &                          RLOW(I),RHIGH(I)
 260 FORMAT(1H ,I3,6X,4A2,5X,F9.3,3X,            F9.3,2X,F9.3)
 250 CONTINUE
 300 CONTINUE
C...
     RETURN
     END
     END$
```

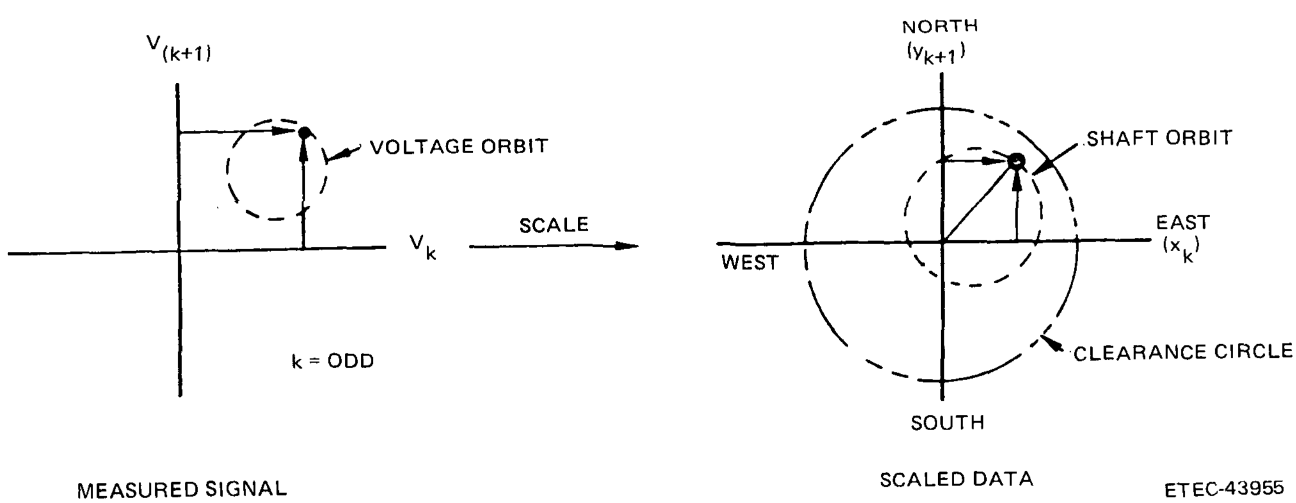
program (ISIP program). There were three proximity probe sets on the ISIP-II pump. Each consisted of two data channels arranged to measure shaft motion in orthogonal directions. Two probe sets were installed in the hydrostatic (sodium) bearing. Output data for the probe sets were:

Bearing probes: Orbit diameter (mils)
Orbit center offset (mils)
Orbit center azimuth, ccw from suction (degrees)
Minimum film thickness (mils)

In the following calculations, each data channel is given a subscript (k) to facilitate identification of data and subsequent calculation derived from the output of that channel.

In sampling data, even-numbered subscripts were sampled immediately after the preceding odd-number subscript in order to minimize error. The odd and then even subscripted data represent x, y coordinates of a point that is moving with time; therefore, x and y were read as nearly simultaneously as possible.

1. Measure and scale output signal voltage from each probe data channel (V_k) at least 40 times per shaft revolution for at least five revolutions (not necessarily five consecutive revolutions).



2. Calculation of orbit diameter (ØRB)

$$(ØRB)_k = \frac{1}{2}\left[(\overline{x}_{kmax} - \overline{x}_{kmin}) + (\overline{y}_{k+1\ max} - \overline{y}_{k+1min})\right]$$

where $\overline{x}$ and $\overline{y}$ are average extreme values, averaged over five revolutions.

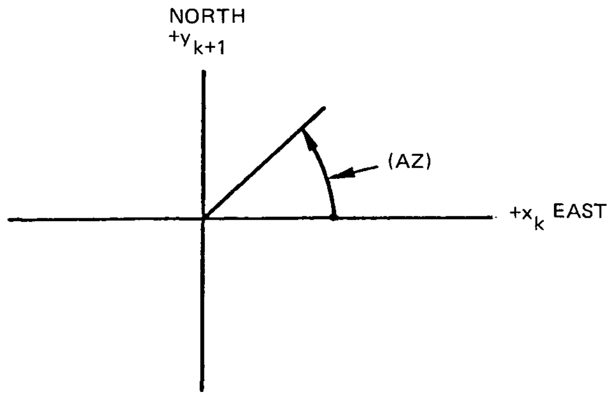
3. Calculation of orbit center offset (ØFF)

$$(ØFF)_k = \frac{1}{2}\sqrt{(\overline{x}_{kmax} + \overline{x}_{kmin})^2 + (\overline{y}_{k+1\ max} + \overline{y}_{k+1\ min})^2}$$

4. Calculation of orbit center azimuth (AZ) for MTI probe

$$(AZ)_k = \text{arc tan}\left[\frac{\overline{y}_{k+1\ max} + \overline{y}_{k+1\ min}}{\overline{x}_{kmax} + \overline{x}_{kmin}}\right]$$

Note: Printout of principal angle was in degrees ccw from positive x axis.



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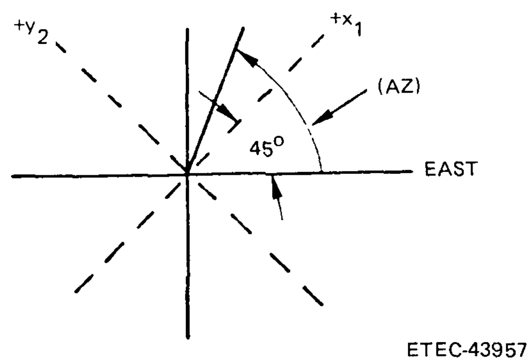
5. Calculation of orbit center azimuth (AZ) for Kaman probes

$$(AZ)_1 = 45^o + \text{arc tan}\left[\frac{\overline{y}_{2max} + \overline{y}_{2min}}{\overline{x}_{1max} + \overline{x}_{1min}}\right]$$



6. Calculation of minimum film thickness (F)

$$(F)_k = D_k - (\emptyset FF)_k - \frac{(\emptyset RB)_k}{2}$$

where D_k = diametral clearance at probe location (input with scaling factors at calibration).

7. Calculation of sodium bearing temperatures

Sample output from TE-02A, TE-02B, TE-02C, TE-02D, TE-0-1, TE-0-2, TE-0-3, TE-0-4

Calculate and print out:

AVG. TEMP.
MAX. TEMP.
MIN. TEMP.

The source program listing for the program BPERF is presented as Table C-3.

C. LDELT, PUMP TANK L-DELTA-T PROGRAM

This section includes original equations and the resultant Fortran program to compute pump tank distortion due to heating.

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 1 of 6)

```
&BPERF T=00004 IS ON CR00013 USING 00043 BLKS R=0160

FTN,L
      PROGRAM BPERF(3,40),    G.A.  SPTF  <810626.0822>
C
C                                      WRITTEN BY RON LEVINE IN 1977
CD                                     MODIFIED BY G.ANDERSON   12/13/78
CD                                     REWRITTEN BY G.ANDERSON   1/20/81
C
C
C
      DIMENSION RMIN(6,5),RMAX(6,5),SC(256),VOLTS(256),
     + IBUF(240),NSEQ(10),IPRAM(5),NSEQR(240)
      COMMON IA(800),RA(400),KDAT(281),ITTL(256,4)
      DATA  NSEQ/152,153,157,154,155,156,129,130,131,132/
     +  ,IRPM/145/,LP/6/,MUX/9/,NUM/240/
C
      CALL RMPAR(IPRAM)
      ITTY=IPRAM(1)
      IF(ITTY.EQ.0)ITTY=1
C
C
C**** MUX,AVERAGE, FIND MAX AND MIN OF TEMPS, AVERAGE OF RPM
C
      RPM=0.0
      TMIN=9999.
      TMAX=-9999
      TAVG=0.0
      DO 40 K=1,5
      CALL EXEC(9,6HMUX    )
      CALL SCAL(2,NT,LP,KDAT,SC,VOLTS,0)
      DO 20 I=7,10
      TEMP=SC(NSEQ(I))
      TAVG=TEMP + TAVG
      IF(TEMP.GT.TMAX)TMAX=TEMP
20    IF(TEMP.LT.TMIN)TMIN=TEMP
40    RPM = RPM + SC(IRPM)
      RPM=RPM/5.0
      RPS=RPM/60.0
      PERIOD=1./RPS
      TAVG=TAVG/20.0
C
C
C**** START DATA ACQUISITION SECTION
C
C SETUP THE RANDOM ADDRESS WORDS
```

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 2 of 6)

```
      C
            DO 60 I=1,40
            IST=(I-1)*6+1
            CALL RANDM(NSEQ,NSEQR(IST),6)
      60    CONTINUE
      C
      C   INITIALIZE THE MAX,MIN ARRAYS
      C
            DO 80 I=1,6
            DO 80 J=1,5
            RMIN(I,J)=99999.
            RMAX(I,J)=-99999.
      80    CONTINUE
      C
      C   TAKE DATA
      C
            DO 100 IPASS=1,5
            CALL BSAMP(MUX,NSEQR,ITTY,LP,IBUF,NUM,PERIOD)
            CALL SAVE(IPASS,IBUF,NSEQ,RMIN,RMAX)
      100   CONTINUE
      C
      C
      C
            IF(ISSW(4).LT.0)WRITE(6,5000)2HRM,2HIN,RMIN
            IF(ISSW(4).LT.0)WRITE(6,5000)2HRM,2HAX,RMAX
       5000 FORMAT(1H ,2A2/,(1X,6(F8.1,1X)))
            CALL VPRPT(RMIN,RMAX,TAVG,TMIN,TMAX,RPM,NSEQ,LP)
            END
      C
      C
      C   THIS SUBROUTINE WILL SET THE PACER TO GET 40 SCANS PER REV
      C
            SUBROUTINE PACER(PERIOD,NUM,MUX,ITTY)
            TPSAMP=PERIOD/NUM
            MULT=-1
      10    MULT=MULT+1
            PER=TPSAMP/(10.**(MULT-6))
            IF(PER.GT.255.)GO TO 10
            IPER=PER
            CALL P2313(MUX,IRTN,0,0,IPER,MULT,0,0)
            RETURN
            END
      C
      C
      C   THIS SUBROUTINE WILL TAKE ONE BUFFER OF 40 SCANS OF 6 CHANNELS TIME
      C  TO LAST ONE REVOLUTION.
```

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 3 of 6)

```
C
      SUBROUTINE BSAMP(MUX,NSEQR,ITTY,LP,IBUF,NUM,PERIOD)
      DIMENSION IBUF(240),JBUF(240),AVE(240),NSEQR(240),
     +          IQBUF(20)
C
C  SET UP THE PACER
C
      CALL B2313(IQBUF,20)
      CALL PACER(PERIOD,NUM,MUX,ITTY)
C
C
C  DO MUX PACED FOR 40 SCANS OF 6 CHANS
C
      CALL GMUX (MUX,1,1,IBUF,JBUF,AVE, NUM,-1,NSEQR,IQBUF)
      IF(ISSW(4).LT.0)WRITE(1,40)IBUF
40    FORMAT(6I7)
      RETURN
      END
C
C
C    THIS SUBROUTINE SAVE THE MIN,MAX VOLTS
C
      SUBROUTINE SAVE(IPASS,IBUF,NSEQ,RMIN,RMAX)
      DIMENSION IBUF(1),RMIN(6,5),RMAX(6,5),NSEQ(1)
      DO 100 I=1,40
      DO 80 J=1,6
      LOC=(I-1)*6+J
      V=VLTS(IBUF(LOC),GAIN(NSEQ(J)))
      IF(V.LT.RMIN(J,IPASS))RMIN(J,IPASS)=V
      IF(V.GT.RMAX(J,IPASS))RMAX(J,IPASS)=V
80    CONTINUE
100   CONTINUE
      RETURN
      END
C
C
C  THIS SUBROUTINE WILL PRINT THE RESULTS
C
      SUBROUTINE VPRPT(RMIN,RMAX,TAVG,TMIN,TMAX,RPM,NSEQ,LP)
C
      DIMENSION ARB(6),AFF(3),AL(3),DMFT(3),
     1 DIAT(10),RMIN(6,5),RMAX(6,5),
     2 NSEQ(10),AVLO( 6),AVHI( 6)
      COMMON IA(800),RA(400),KDAT(281),ITTL(256,4)
      EQUIVALENCE (DIAT,RA(14))
      DATA PI4/0.7854/,DGPRAD/57.296/,PI/3.1416/
```

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 4 of 6)

```
C**** FIND AVERAGE MIN AND AVERAGE MAX - FOR 5 REV'S
      DO 100 I=1,6
      AVLO(I)=0.0
      AVHI(I)=0.0
      DO 80 J=1,5
      AVLO(I)=AVLO(I)+RMIN(I,J)
      AVHI(I)=AVHI(I)+RMAX(I,J)
80    CONTINUE
      AVLO(I)=AVLO(I)/5.0
      AVHI(I)=AVHI(I)/5.0
100   CONTINUE
      IF(ISSW(4).LT.0)WRITE(LP,5030)2HAV,2HLO,2HMV ,AVLO
      IF(ISSW(4).LT.0)WRITE(LP,5030)2HAV,2HHI,2HMV,AVHI
 5030 FORMAT(/,1H ,2A2,1X,A2/,1X,(6(1H ,F7.1,X)))
C**** SCALE AVLO, AVHI
      CALL VSCAL(AVLO,NSEQ,6,AVLO)
      CALL VSCAL(AVHI,NSEQ,6,AVHI)
      IF(ISSW(4).LT.0)WRITE(LP,5030)2HAV,2HLO,2HML,AVLO
      IF(ISSW(4).LT.0)WRITE(LP,5030)2HAV,2HHI,2HML,AVHI
C  CALCULATE ORBIT DIAMETER
C
C
C
C
      J=0
  292 DO 430 I=1,5,2
      J=J+1
  430 ARB(J)=.5*ABS((AVHI(I)-AVLO(I)+AVHI(I+1)-AVLO(I+1)))
C THE FIRST FOUR ARB VALUES ARE PRINTED ON THE FORMAT
C AS ORBIT DIAMETER (MILS) SET 1,2,3,4
C THESE ARE ARB(1),ARB(2),ARB(3),ARB(4)
C
C  THE NEXT TWO VALUES ARE PRINTED ON THE BOTTOM AS
C  MID SPAN ARBIT(VOLTS),AND UPPER SHFAFT ARBIT(MILS)^
C  THESE ARE ARB(5) AND ARB(6)
C
C
C
C  CALCULATION OF ORBIT CENTER OFSET(AFF)
C  CALCULATION OF ORBIT CENTER OFSET(AFF)
      J=0
      DO 450 I=1,5,2
      J=J+1
      XMIN=AVLO(I)
      XMAX=AVHI(I)
      YMIN=AVLO(I+1)
```

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 5 of 6)

```
        YMAX=AVHI(I+1)
        AFF(J)=0.5*SQRT(((XMAX+XMIN)**2)+((YMAX+YMIN)**2))
 4040   FORMAT(1H ,2I5,2X,5(F6.1,2X))
  450   CONTINUE
C
C
C
C  CALCULATE ORBIT CENTER AZIMUTH AL FOR MTI PROBE
C
        J=0
  452   DO 470 I=1,5,2
        J=J+1
        LOC=450+I
        SUMI=AVHI(I)+AVLO(I)
        IF(SUMI.EQ.0) GO TO 5500
        AL(J)=(AVHI(I+1)+AVLO(I+1))/SUMI
        LOC=460+I
        IF(AL(J).EQ.0) GO TO 5500
        ARG=AL(J)
        THETA=ATAN(ARG)
        RADNS=THETA
        IF(THETA.GT.0.AND.SUMI.LT.0)RADNS=THETA + PI
        IF(THETA.LT.0.AND.SUMI.GT.0)RADNS=2.0*PI + THETA
        IF(THETA.LT.0.0.AND.SUMI.LT.0.0)RADNS=THETA + PI
        AL(J)=RADNS*DGPRAD
        IF(ISSW(4).LT.0)
      1WRITE(LP,4040)I,J,AVLO(I),AVHI(I),AVLO(I+1),AVHI(I+1),AL(J)
  470   CONTINUE
C
C NOTE AL(I) SHOULD BE THE PRINCIPAL ANGLE IN DEGREES
C FROM THE POSITIVE X AXIS
C PI/2 TO -PI/2
C
C  CALCULATION OF THE AZIMUTH FOR THE KAMEN PROBE
C 211   SUMI=AVLO(1)+AVHI(1)
C       LOC=470
C       IF(SUMI.EQ.0) GO TO 5500
C       AL(1)=(AVHI(2)+AVLO(2))/SUMI
C       ARG=AL(1)
C       THETA=ATAN(ARG)
C       IF(THETA.GT.0.0.AND.SUMI.LT.0)THETA=THETA + PI
C       IF(THETA.LT.0.AND.SUMI.GT.0.0)THETA=2.0*PI + THETA
C       IF(THETA.LT.0.0.AND.SUMI.LT.0.0)THETA=THETA + PI
C       AL(1)=(THETA+PI4)*DGPRAD
C       IF(AL(1).GT.360.0)AL(1)=AL(1)-360.0
C CALCULATION OF MAXIMUN FILM THICKNESS
```

TABLE C-3

BPERF SOURCE PROGRAM LISTING
(Sheet 6 of 6)

```
C
C THESE WILL BE PRINTED AS FILM THICKNESS(MILS)
C
500     J=0
        DO 427 IMN=1,5,2
        J=J+1
 427    DMFT(J)=DIAT(IMN)/2.0-AFF(J)-ARB(J)/2.
        LP=6
        NREV=5
        WRITE(LP,800)NREV,RPM
   800 FORMAT(1H ,/," BEARING PERFORMANCE ", 5X,"REV-810121"/
      + ," ",I2," REV AVERAGES",
      1 / 1H ,"RPM=",F7.1
      &/,31X,"SET 1",7X,"SET 2",6X,"SET 3")
        WRITE(LP,805)(ARB(I),I=1,3)
   805 FORMAT(1H ," ORBIT DIAMETER (MILS)" 6X,F7.4,5X,F7.4,5X,F7 4)
        WRITE(LP,810)AFF
   810 FORMAT(1H ," ORBIT CTR. OFFSET (MILS)"3X,F7.4,5X,F7.4,5X,F7.4)
        WRITE(LP,815)AL
   815 FORMAT(1H ," ORBIT CTR. AZIMUTH"/" (CCW FROM SUCT.) (DEG.)" 6X,
      &F6.2,6X,F6.2,6X,F6.2)
        WRITE(LP,820)DMFT
   820 FORMAT(1H ," FILM THICKNESS (MILS)" 6X,F7.4,5X,F7.4,5X,F7.4,
      +  ," (BASED ON AVERAGE VALUES)")
        WRITE(LP,825)TAVG,TMAX,TMIN
   825 FORMAT(1H ,"          SODIUM BEARING TEMPERATURE: ",/,10X,
      &" AVG. TEMP.   "F6.1,"      MAX. TEMP.   "F6.1"     MIN. TEMP" F6.1,/)
C       WRITE(LP,830)ARB(5),ARB(6)
C 830 FORMAT(1H ," SHAFT PROXIMITY PROBES: INDICATION ONLY"/,/,
C     &"     MID. SPAN ORBIT (MILS)        ",F6.3,/
C     &"     UPPER SHAFT ORBIT (MV'S)       ",F6.2,/)
        GO TO 6000
5500    WRITE( 1,5600)LOC
 5600 FORMAT(1H ,    "BPERF BAD DATA   ,     LOC = ",I3,
      %   "  ZE84,ZE85 PAIR IS BAD, WE KNOW ABOUT IT."
        GO TO 500
C
 6000 CONTINUE
C
 6500 RETURN
        END
        END$
```

Unheated Zone

Calculate L•ΔT's (see Table C-4 for input data x_j and $T_{j,k}$).

S-N L-DELTA-T (k = 1):

$$(L \cdot \Delta TU)_k = 7.0 \left[T_{1,(K+4)} - T_{1,k}\right]$$

$$+ \sum_{j=1}^{j=4} x_j \left[T_{(j+1),(k+4)} - T_{(j+1),k} + T_{j,(k+4)} - T_{j,k}\right]$$

SW-NE L-DELTA-T (k = 2): Repeat above equation.

W-E L-DELTA-T (k = 3): Repeat above equation.

NW-SE L-DELTA-T (k = 4): Repeat above equation.

Calculate maximum diametral ΔT.

Outer loop: DO for j = 1 through j = 5

Inner loop: DO for k = 1 through k = 4

$$(\Delta T)_{j,k} = \left|\left[T_{j,(k+4)} - T_{j,k}\right]\right| \text{ absolute value}$$

Calculate maximum temperature difference at each level (j).

Loop: DØ for j = 1 through j = 5

$(\Delta T_{max})_j$ = maximum value $(\Delta T_{j,k})$

where k = 1 through k = 4

TABLE C-4

MATRIX

ELEVATION DOWN FROM TOP FLANGE (in.)	j \ k	NORTH 1	NORTHEAST 2	EAST 3	SOUTHEAST 4	SOUTH 5	SOUTHWEST 6	WEST 7	NORTHWEST 8
14	1	TE-14-1	TE-14-2	TE-14-3	TE-14-4	TE-14-5	TE-14-6	TE-14-7	TE-14-8
26	2	TE-26-1	TE-26-2	TE-26-3	TE-26-4	TE-26-5	TE-26-6	TE-26-7	TE-26-8
44	3	TE-44-1	TE-44-2	TE-44-3	TE-44-4	TE-44-5	TE-44-6	TE-44-7	TE-44-8
62	4	TE-62-1	TE-62-2	TE-62-3	TE-62-4	TE-62-5	TE-62-6	TE-62-7	TE-62-8
74	5	TE-72-1	TE-72-2	TE-72-3	TE-72-4	TE-72-5	TE-72-6	TE-72-7	TE-72-8
104	6	TE901-71		TE1-5-3		TE955A		TE1-5-7	
162	7	TE954A		TE1-4-3		TE901-66		TE1-4-7	
236	8	TE901-65		TE1-3-3		TE953A		TE1-3-7	
308	9	TE952A		TE1-2-3		TE901-62		TE1-2-7	

VERTICAL HALF-DISTANCES
(x_j)

14	26	44	62	74	104	162	236	308
in.								
j	1	2	3	4	5	6	7	8
x_j	6.0	9.0	9.0	6.0	15.0	29.0	37.0	36.0

Heated Zone

Calculate L•ΔT's.

S-N L-DELTA-T (k = 1):

$$'(L \cdot \Delta TH)_j = \sum_{j=6}^{j=8} x_j \left[T_{(j+1),(k+4)} - T_{(j+1),k} + T_{j,(k+4)} - T_{j,k}\right]$$

W-E L-DELTA-T (k = 3): Repeat above equation.

Calculate maximum diametral ΔT.

Outer loop: DO for j = 6 through j = 9

Inner loop: DO for k = 1 and k = 3

$$(\Delta T)_{j,k} = \left|\left[T_{j,(k+4)} - T_{j,k}\right]\right| \text{ absolute value}$$

Calculate maximum temperature difference at each level (j).

Loop: DO for j = 6 through j = 9

$(\Delta T_{max})_j$ = maximum value $(\Delta T_{j,k})$

where k = 1 and k = 3

Overall L•ΔT

S-N L-DELTA-T (k = 1):

$$(L \cdot \Delta T\emptyset)_k = (L \cdot \Delta TU)_k + x_5 \left[T_{6,(k+4)} - T_{6,k} + T_{5,(k+4)} - T_{5,k}\right] + (L \cdot \Delta TH)_k$$

W-E L-DELTA-T (k = 3): Repeat above equation.

Input Data — Temperatures (T_{jjk})

A typical L-delta-T program printout is presented as Figure C-1. The source program listing for the program L-DELT is presented as Table C-5.

```
               ISIP PUMP L-DELTA-T PROGRAM REQUIREMENTS      REV-810320

8/14/81       0:59:59      HARDWARE TIME :  226    1   0   1 242
**************************************************************************
TP-10-PP-038
ISIP II   2000 HR ENDURANCE RUN
**************************************************************************
L-DELTA-T OUTPUT PARAMETERS

THIS INFORMATION IS TO BE TREATED AS RAW DATA, NOT FOR OFFICIAL
USE UNLESS APPROVED BY ENGINEERING:                   APPROVAL---------
                                                      DATE     ---------


                    UNHEATED ZONE TEMPERATURE DISTRIBUTION
LEVEL     N       NE       E       SE       S       SW       W       NW      DDTM
-----     -       --       -       --       -       --       -       --      ----
  14    232.2   230.4   230.4   231.3   230.4   232.2   235.7   233.1      5.3
  26    315.8   309.4   311.2   314.9   311.2   314.0   317.6   318.5      6.3
  44    430.7   426.3   432.5   436.1   434.3   431.6   449.4   441.4     16.9
  62    568.8   564.5   572.3   585.3   581.9   577.5   603.5   586.2     31.2
  74    661.3   651.9   670.8   684.5   677.6   670.8   696.5   675.9     25.7

UNHEATED L-DELTA-T                      267.0   495.9  1090.1   134.5


                     HEATED ZONE TEMPERATURE DISTRIBUTION
LEVEL     N       NE       E       SE       S       SW       W       NW      DDTM
-----     -       --       -       --       -       --       -       --      ----
 104    960.5           966.4           963.9           963.9              3.4
 162    988.4           980.8           982.5           979.9              5.9
 236    948.6           945.2           946.9           946.9              1.7
 308    946.9           946.9           946.9           941.8              5.1

HEATED L-DELTA-T                       -415.3          -187.9


TOTAL L-DELTA-T  EW          1250.5


TOTAL L-DELTA-T  SN           147.3
```

Figure C-1. ISIP-II Pump L-DELTA-T Printout

TABLE C-5

LDELT SOURCE PROGRAM LISTING
(Sheet 1 of 5)

```
&LDELT T=00003 IS ON CR00012 USING 00033 BLKS R=0000

FTN,L
        PROGRAM LDELT(),   G.A.  REV-810320  SPTF
C
C
C
C                                        G.ANDERSON    11/19/76
CD                                                      6/27/79
C
        DIMENSION X(8),T(9,8),XLDTU(4),XLDTH(3),DTU(5,4),
      +           DTH(9,3),TMAXU(5),TMAXH(9),XLDTO(3),IBUF(81),
      +           LEVEL(9),IPRAM(5),IPROC(7),ISTEP(7),
      +           NDOR(56,3),IDATA(2),ITIME(5),SC(256),IHT(5)
        COMMON IA(800),RA(400),KDAT(281),ITTL(256,4)
        DATA X/6.0,9.0,9.0,6.0,15.0,29.0,37.0,36.0/,
      +      ILP/6/,NAM1/2HUN/,NAM2/2H  /,NAM3/2HEW/,
      +      NAM4/2HSN/,LEVEL/14,26,44,62,74,104,162,236,308/,
      +      LU/24/,MAXPT/56/,
      +      NDOR/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,
      +21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,
      +41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,
      +1,2,3,4,5,1,2,3,4,5,1,2,3,4,5,1,2,3,4,5,
      +1,2,3,4,5,1,2,3,4,5,1,2,3,4,5,1,2,3,4,5,
      +6,7,8,9,6,7,8,9,6,7,8,9,6,7,8,9,
      +5*1,5*2,5*3,5*4,5*5,5*6,5*7,5*8,4*1,4*3,4*5,4*7/
C NDOR(N,1)=MUX SEQ NUMBER
C NDOR(N,2)=FIRST INDEX TO T
C NDOR)N,3)=SECOND INDEX TO T
C
C
C  INITIALIZE UNUSED PARTS OF ARRAY T.
C
        DO 80 K=2,8,2
        DO 75 J=6,9
        T(J,K)=-9998.
75      CONTINUE
80      CONTINUE
C
C  GET TEMPERATURES INTO ARRAY T FOR ANALYSIS.
C
C
        CALL AVERA(SC,0)
        DO 200 J=1,56
        T(NDOR(J,2),NDOR(J,3))=SC(J)
200     CONTINUE
```

TABLE C-5

LDELT SOURCE PROGRAM LISTING
(Sheet 2 of 5)

```
205   DO 240 K=1,8
      DO 220 J=1,9
      IF(T(J,K).NE.-9999..AND.T(J,K).NE.9999.)GO TO 220
      WRITE(ITTY,210)J,K
210   FORMAT("T("I1","I1")=+-9999. TEMP IS OPEN?")
220   CONTINUE
240   CONTINUE
      IF(ISSW(10).LT.0)CALL CKOUT(T)
C
C
C
C  UNHEATED ZONE CALCULATIONS
C
      DO 300 K=1,4
      CALL DELTA(K,1,4,T,X,XLDTU(K))
300   CONTINUE
C  GET DELTA T'S
      DO 340 J=1,5
      TMAXU(J)=-999999.
      DO 320 K=1,4
      DTU(J,K)=ABS(T(J,K+4)-T(J,K))
      IF(DTU(J,K).GT.TMAXU(J))TMAXU(J)=DTU(J,K)
320   CONTINUE
340   CONTINUE
C
C
C
C  HEATED ZONE CALCULATIONS
C
      CALL DELTA(1,6,8,T,X,XLDTH(1))
      CALL DELTA(3,6,8,T,X,XLDTH(3))
      DO 400 J=6,9
      DTH(J,1)=ABS(T(J,5)-T(J,1))
      DTH(J,3)=ABS(T(J,7)-T(J,3))
      TMAXH(J)=AMAX1(DTH(J,1),DTH(J,3))
400   CONTINUE
C
C
C
C  OVERALL L-DELTA-T
      XLDTO(1)=XLDTU(1)+X(5)*(T(6,5)-T(6,1)+T(5,5)-T(5,1))+XLDTH(1)
      XLDTO(3)=XLDTU(3)+X(5)*(T(6,7)-T(6,3)+T(5,7)-T(5,3))+XLDTH(3)
C
C
C  OUTPUT RESULTS
C
```

TABLE C-5

LDELT SOURCE PROGRAM LISTING
(Sheet 3 of 5)

```
      WRITE(ILP,500)
500   FORMAT("1"15X,"ISIP PUMP L-DELTA-T PROGRAM REQUIREMENTS",
     +5X"REV-810320"// )
      CALL RDCLK(IHT(1),IHT(2),IHT(3),IHT(4),IHT(5))
      CALL EXEC(11,ITIME,IYEAR)
      CALL DATE(ITIME(5),MONTH,IYEAR)
      WRITE(ILP,520)MONTH,ITIME(5),IYEAR,(ITIME(I),I=4,2,-1),IHT
520   FORMAT( I2,"/"I2"/"I2,5X,I2":"I2":"I2,6X,"HARDWARE TIME : "5I4)
      CALL INSRT(ILP)
      WRITE(ILP,540)
540   FORMAT(  " L-DELTA-T OUTPUT PARAMETERS"/ )
      WRITE(ILP,580)
580   FORMAT(  " THIS INFORMATION IS TO BE TREATED AS RAW DATA, "
     +"NOT FOR OFFICIAL",/,
     +" USE UNLESS APPROVED BY ENGINEERING:"20X"APPROVAL",9("-"),/,
     +56X"DATE"4X,9("-")/)
      WRITE(ILP,600)NAM1
600   FORMAT( //,20X,A2,"HEATED ZONE TEMPERATURE DISTRIBUTION",/ ,
     +" LEVEL"4X"N"6X"NE"7X"E"6X"SE"7X"S"6X"SW"7X"W"6X"NW"5X"DDTM",/,
     +1X,5("-"),4X"-"6X"--"7X"-"6X"--"7X"-"6X"--"7X"-"6X"--"5X"----",)
      DO 640 J=1,5
      WRITE(ILP,620)LEVEL(J),(T(J,K),K=1,8),TMAXU(J)
620   FORMAT(1X,I4,2X,9(F6.1,2X))
640   CONTINUE
      WRITE(ILP,660)(XLDTU(J),J=1,4)
660   FORMAT( /" UNHEATED L-DELTA-T "19X,4(F6.1,2X))
      WRITE(ILP,600)NAM2
      DO 680 J=6,9
      WRITE(ILP,670)LEVEL(J),(T(J,K),K=1,7,2),TMAXH(J)
670   FORMAT(1X,I4,2X,4(F6.1,10X),F6.1)
680   CONTINUE
      WRITE(ILP,700)XLDTH(1),XLDTH(3)
700   FORMAT(/" HEATED L-DELTA-T"22X,2(F6.1,10X))
      WRITE(ILP,720)NAM3,XLDTO(3)
      WRITE(ILP,720)NAM4,XLDTO(1)
720   FORMAT(//" TOTAL L-DELTA-T  "A2,10X,F7.1)
      END
      SUBROUTINE DELTA(K,N1,N2,T,X,DELT)
C
C  THIS SUBROUTINE WILL FIND THE L-DELTA-T'S FOR
C  BOTH THE HEATED AND THE UNHEATED ZONES.
C
      DIMENSION X(8),T(9,8)
      DELT=0.0
C
C  SUMMATION LOOP
```

TABLE C-5

LDELT SOURCE PROGRAM LISTING
(Sheet 4 of 5)

```
C
      DO 100 J=N1,N2
      DELT=DELT+X(J)*(T(J+1,K+4)-T(J+1,K)+T(J,K+4)-T(J,K))
  100 CONTINUE
      IF(N1.EQ.6)RETURN
      DELT=DELT+7.0*(T(1,K+4)-T(1,K))
      RETURN
      END
      SUBROUTINE CKOUT(T)
      DIMENSION T(9,8)
      T(1,1)=240.5
      T(2,1)=327.6
      T(3,1)=451.0
      T(4,1)=598.2
      T(5,1)=696.6
      T(6,1)=1047.
      T(7,1)=1020.
      T(8,1)=1013.
      T(9,1)=950.0
      T(1,2)=238.8
      T(2,2)=327.6
      T(3,2)=445.0
      T(4,2)=592.2
      T(5,2)=688.2
      T(1,3)=238.8
      T(2,3)=325.0
      T(3,3)=454.5
      T(4,3)=604.1
      T(5,3)=711.6
      T(6,3)=1055.
      T(7,3)=1025.
      T(8,3)=1015.
      T(9,3)=950.0
      T(1,4)=242.3
      T(2,4)=325.0
      T(3,4)=460.5
      T(4,4)=621.0
      T(5,4)=726.1
      T(1,5)=243.1
      T(2,5)=328.5
      T(3,5)=460.5
      T(4,5)=618.4
      T(5,5)=726.7
      T(6,5)=1020.
      T(7,5)=1026.
      T(8,5)=1010.
```

TABLE C-5

LDELT SOURCE PROGRAM LISTING
(Sheet 5 of 5)

```
T(9,5)=956.0
T(1,6)=245.7
T(2,6)=327.6
T(3,6)=458.8
T(4,6)=614.2
T(5,6)=711.6
T(1,7)=250.0
T(2,7)=336.4
T(3,7)=472.6
T(4,7)=636.1
T(5,7)=737.5
T(6,7)=1060.
T(7,7)=1046.
T(8,7)=1026.
T(9,7)=966.0
T(1,8)=245.7
T(2,8)=336.4
T(3,8)=461.4
T(4,8)=615.1
T(5,8)=710.0
RETURN
END
END$
```

D. REDUC, PARAMETER BOX DISPLAY

The function of the computer program REDUC was to compute three of the critical pump operating parameters and present them on a TV screen for the convenience of the operators.

The program used the same computational techniques as the computer program ISIP. The REDUC program computed for TV display (1) head ratio vs flow-divided-by-speed (Q/N) ratio and (2) NPSH vs Q/N for two ranges of NPSH.

The head ratio vs Q/N display was used for the cavitation test. The computed head was compared to the pretest noncavitating head. This ratio was displayed on the TV screen and allowed the operator to readily judge when the 97% head limit point was reached. The 100% head ratio and the 97% head drop limit lines were displayed on the TV screen as visual references.

A display of NPSH vs Q/N was also available to the operator for test conditions other than the cavitation test. NPSH vs Q/N could be displayed for NPSH in the range of 60 ft or for NPSH in the range of 29 ft. The 29-ft NPSH range was used for the reduced NPSH endurance run. The 60-ft range could be used for nearly all other conditions.

The source program listing for the computer program REDUC is presented as Table C-6.

TABLE C-6

REDUC SOURCE PROGRAM LISTING
(Sheet 1 of 2)

```
&REDUC T=00004 IS ON CR00013 USING 00011 BLKS R=0000

FTN,L
      SUBROUTINE REDUC(AVG,VCALC),   G.A.  SPTF  <810702.2220>
C
C                                            G.ANDERSON 7/6/79
CD                                                      7/20/79
C
C   THIS ROUTINE WAS WRITTEN PER MANNY TESSIER'S LETTER
C OF 7-79. IT WILL MAKE THE SPECIAL CALCS FOR THE TV TARGET
C BOX OUTPUT.
C
C     SE20 IS SE47,  6 30 81
C
C  THIS SUBROUTINE WILL CALCULATE SEVERAL SPECIAL PARAMETERS
C FROM MUXED DATA(AVG) AND RETURN THEM IN VCALC.
C
      DIMENSION AVG( 1 ),VCALC(10)
      DATA E/2.71828/,QSTD/14500./,A,B,C/703.88,-.65532E-2,-.49893E-6/
      THIRD=1./3.
      TE120 = AVG (181)
      TE119 = AVG (180)
      F101BM = AVG ( 80)
      XLT42 = AVG (162)
      SE20 = AVG (145)
      PT113 = AVG (178)
      PT105 = AVG (159)
      XLT40 = AVG (144)
      IF(SE20.LT.0.0)SE20=0.
      IF(F101BM.LT.0.0)F101BM=0.
C
      RHOIN = 59.566- .00795*TE120 -2.872E-7*TE120**2+ 6.04E-11*TE120**3
      RHOUT = 59.566- .00795*TE119 -2.872E-7*TE119**2+ 6.04E-11*TE119**3
      SIGIN = RHOIN / 62.4
      SIGOUT= RHOUT / 62.4
      TKIN = (TE120 + 459.67) / 1.8
      TKOUT= (TE119 + 459.67) / 1.8
      IF(TE119.LE.932.)XMU=2.419/3600.*(.1235*SIGOUT**THIRD*E**
     +                     (697.*(SIGOUT/TKOUT)))
      IF(TE119.GT.932.)XMU=2.419/3600.*(.0851*SIGOUT**THIRD*E**
     +                     (1040.*(SIGOUT/TKOUT)))
      VP = 10.**(6.354-(5567./TKIN)-.4343/2.*ALOG(TKIN))*14.7*144/RHOIN
C
C    D1=23.5        D2=15.25
C
      VIN= 7.400E-4 * F101BM
```

TABLE C-6

REDUC SOURCE PROGRAM LISTING
(Sheet 2 of 2)

```
      VOUT = VIN * 2.375
      YIN = VIN **2 / 64.4
      YOUT = VOUT **2 / 64.4
      RE = RHOUT * VOUT * (15.25 / 12.) / XMU
      FO = .0055 * (1.+(2.3607+1.E6/RE)**THIRD)
      HDLS = 2.96 * FO * YOUT
      SLEV = (XLT40 - 26.) / 12.
      IF(XLT40.LT.115.0)SLEV = (XLT42 - 26.) / 12.
      HCG = 144. * PT113 / RHOIN
      HS = SLEV + HCG + YIN
C
C  ELV1=15.04, ELV2=5.28,  INLET C.L. TO INDUCER=3.96 FT.
C
      HD = 144. * (PT105 + 13.8) / RHOUT - 15.04 + HDLS + YOUT
      HT = HD - HS
      XNPSH = HS - HVP + 5.28
      XNPSHI=XNPSH-3.96
      Q1N1 = F101BM / SE20
      HTC1 = HT * (1110. / SE20) **2
      FLOW=F101BM*1110./SE20
      HCORR= B*( QSTD - FLOW  ) + C * ( QSTD **2- FLOW **2)
      HSTD = A + B*QSTD + C*QSTD**2
      HSTD=516.12
      HTC2=HTC1+HCORR
      HR = HTC2 / HSTD
      VCALC(1) = HR
      VCALC(2) = XNPSH-3.96
      VCALC(3) = Q1N1
      RETURN
      END
      END$
```

APPENDIX D
POST-TEST DATA REDUCTION FOR CAVITATION PERFORMANCE TEST

APPENDIX D
POST-TEST DATA REDUCTION FOR CAVITATION PERFORMANCE TEST

DETERMINATION OF NPSH AND FLOW AT 3% HEAD DROP

The following steps describe a graphical technique of determining the NPSH at the 3% head loss point and the starting flow rate required to achieve 14,500 gpm at the 3% head loss point.

The actual data reduction was performed with a computer, using the calculation techniques discussed below.

Step 1 — Correct all measured values of head (H), flow (Q), and NPSH (H_{sv}) from the test speed (N) to 1110 rpm, using the affinity laws:

$$H_c = H \left(\frac{1110}{N}\right)^2$$

$$H_{svc} = H_{sv} \left(\frac{1110}{N}\right)^2$$

$$Q_c = Q \left(\frac{1110}{N}\right)$$

where

H_c = corrected head
H_{svc} = corrected NPSH
Q_c = corrected flow

(Note: All measured NPSH values are reported using the elevation of the tip of the inducer blade leading edge as the reference elevation.)

Step 2 — Using test results from the 950°F pretest flow scan, plot the head-flow points (corrected to 1110 rpm) for the test data taken at nominally 13,800 gpm, 14,500 gpm, 15,200 gpm, and 15,900 gpm. Then draw a smooth curve through the test points (Curve A of Figure D-1).

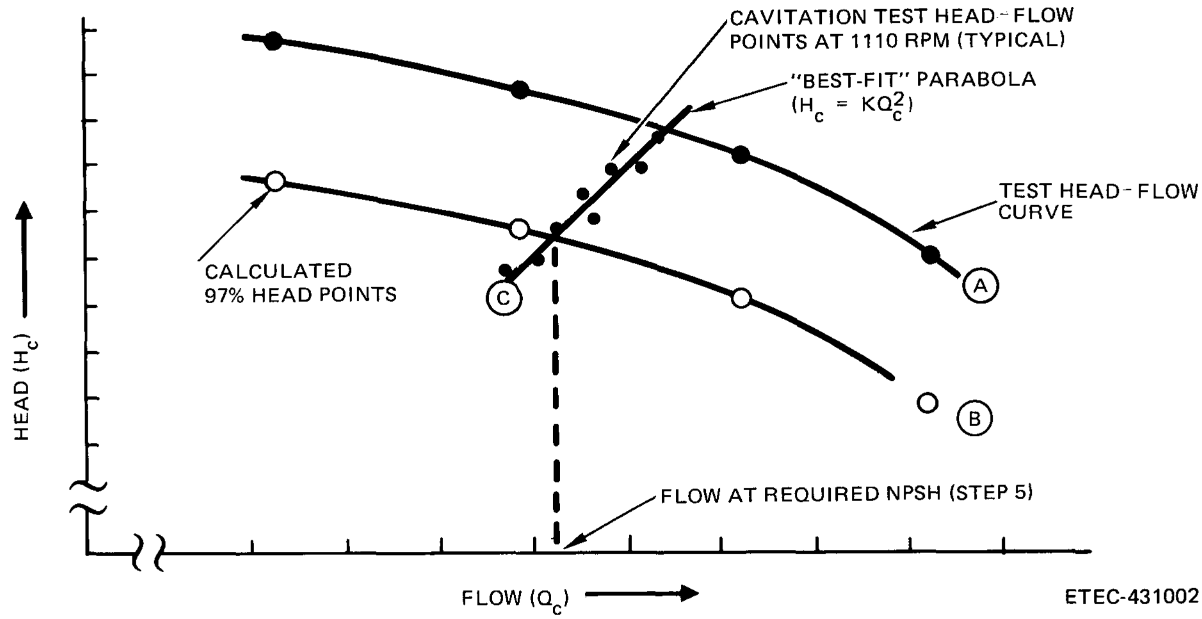


Figure D-1. Graphical Method for Determining Flow at Required NPSH

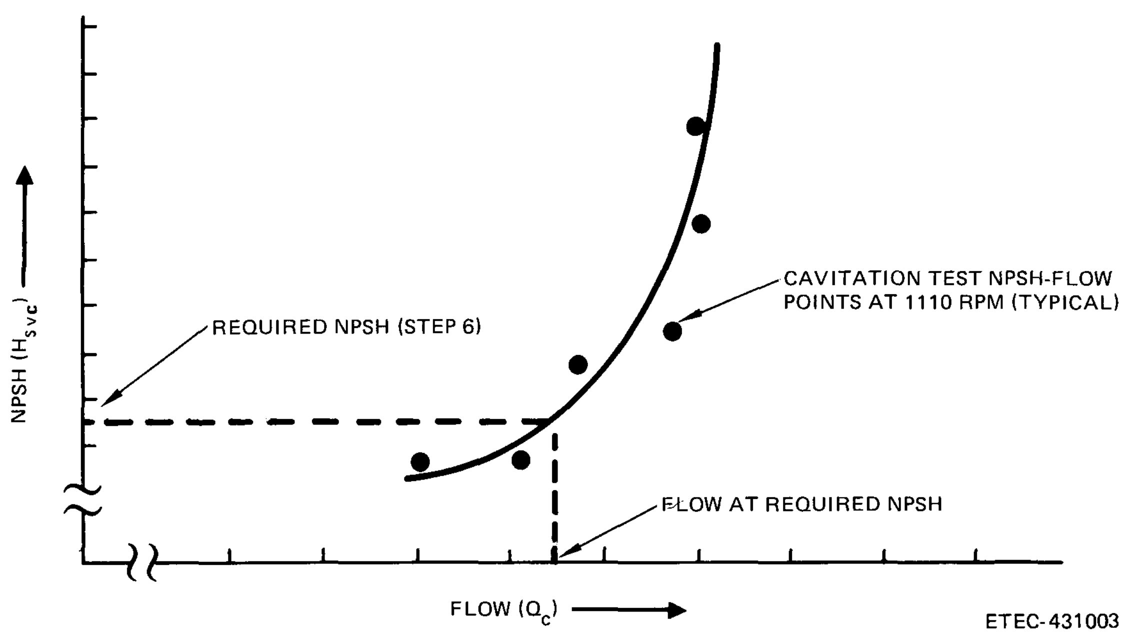


Figure D-2. Graphical Method for Determining Required NPSH

Step 3 — Using 97% of the head values used to plot the test curve in Step 2, and the same flow values, plot a second head-vs-flow curve (Curve B of Figure D-1).

Step 4 — Starting from the test point at the lowest NPSH value, accurately plot each test point (H_c, Q_c) from the cavitation performance test until the plotted points reach the averaged noncavitating head measured prior to the cavitation pretest flow scan.

Step 5 — Draw a "best-fit" parabola, of the form $H_c = KQ_c^2$ through the plotted test points, crossing the 97% head curve (Curve C of Figure D-1). "Best fit" may be determined analytically by using the average value for K, based on all valid test points (see Figure D-1). Note and record the value of Q_c at which the parabola crosses the 97% head curve.

Step 6 — Plot each test point (H_{svc}, Q_c) in the flow regime of Step 4 and draw a "best-fit" curve by eye. Note and record the corrected NPSH value (H_{svc}) corresponding to the flow value recorded in Step 5 (see Figure D-2).