OPERATING EXPERIENCE WITH HEAT TRANSFER
SYSTEM PUMPS AT THE
HALLAM NUCLEAR POWER FACILITY

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OPERATING EXPERIENCE WITH HEAT TRANSFER SYSTEM PUMPS AT THE HALLAM NUCLEAR FACILITY

I. INTRODUCTION

At the Hallam Nuclear Power Facility (HNPF) six pumps are used to circulate sodium in the heat transfer system for the purpose of transferring heat from the reactor to the steam generators. These pumps, which have been in operation since March, 1962, have required maintenance and minor modifications to assure satisfactory operation. It is the purpose of this report to describe the operating and maintenance experience obtained at HNPF on the sodium heat transfer pumps.

II. DESCRIPTION OF PUMPS

Six vertically mounted pumps of the centrifugal, overhung, free surface type are utilized at the HNPF to circulate the heat transfer medium (sodium). Three independent sodium heat transfer circuits are used to remove heat from the reactor; all essentially identical. There are three primary coolant pumps and three secondary coolant pumps. The three primary pumps circulate sodium (radioactive) from the reactor core to the three associated intermediate heat exchangers (IHX's) and back to the reactor. Heat is transferred in the IHX's to the secondary (non-radioactive) sodium, which is circulated by the secondary pumps, to the three independent steam generators. The primary pumps are located below the floor level, but at an elevation such that the piping from the pump drains back to the reactor vessel. The intermediate heat exchangers are located at an elevation higher than that of the primary sodium pumps. Similarly, the secondary sodium pumps and steam generators are located at a still higher elevation. Overall arrangement is designed to provide about 8% free convection cooling of the reactor should all sodium pumps fail simultaneously.

Essential features of these pumps (manufactured by the Byron-Jackson Company) are shown in figure 1. The primary sodium pump cases are permanently cast in the concrete primary system biological shielding and welded into the piping system. The upper portion of the pump extends upward through the shielding to the reactor room with the pump motors mounted in the reactor room at floor level.

Design of the pumps is such that the internal parts, including impeller, shaft, pump barrel, gas seals and bearings can be removed through the top without disturbing the pump case or piping. This also allows ready access for maintenance to the pump driver assembly without radiation considerations.

The secondary sodium pumps are located in the steam generator room, and are almost identical to the primary pumps except that they do not require shielding, and hence, are approximately five feet shorter. As with the primary pumps, the internal parts of the secondary pumps can be removed without disturbing the pump case or piping.

The entire pump assembly fits within the outer case and is supported by the pump case top flange. This assembly consists of a shaft, impeller, bearings, diffuser and inner barrel [which provides support for the bearings and houses the shielding (primary) and thermal insulation]. The 18 vane diffuser is attached to the bottom of the inner barrel by means of bolts. The pump shaft is supported by a ball thrust bearing located above the top pump flange and the impeller (8 vane) is welded to the shaft. Radial support for the shaft is provided by the hydrostatic bearing, which is an integral part of the inner barrel. Sodium is supplied to the bearing from the pump discharge through eight 9/32 in. diameter holes. A gas-tight seal is effected at the upper end of the shaft by means of a circulating-oil-filled, double mechanical seal. In addition to the sealing function the circulating oil serves to lubricate the shaft thrust bearing. Should leakage occur across the lower mechanical seal (O-ring) two sumps of sufficient size to accommodate the entire volume of the seal oil system are provided below the seal. Sight-glasses on each sump tell the operator whether leakage has occurred.

With the pump in operation, about 5% of the total sodium flow is pumped into the pump casing. This sodium is handled by the overflow line, which routes the sodium back to the pump suction in the case of the primary pumps, or to the expansion tank in the case of the secondary pumps. All pumps are driven by constant-speed A-C induction motors, through a variable speed eddy current coupling.

A helium atmosphere is maintained above the free sodium surface in the pumps at all times. A vent line on each pump casing connects the atmosphere of the primary pumps with that of the reactor, and the secondary pumps with that of the secondary expansion tanks. Thus, with the pumps not operating, the sodium level in the primary pumps is the same as reactor level, and the sodium level in the secondary pumps is the same as that in the secondary expansion tank.

Design parameters of the sodium pumps are summarized in Table I.

TABLE I
HNPF SODIUM PUMP DESIGN PARAMETERS

	Primary	Secondary
Capacity (gpm)	7200	7200
Total dynamic head (ft)	160	170
NPSH required (ft)	17	17
NPSH available (ft)	25.5	50
Motor speed (rpm)	900	900
Motor horsepower (hp)	350	350
Overflow (% of total flow)	5	5
Case design pressure (psig)	100	100
Case design temperature (F)	1000	1000

III. OPERATING AND MAINTENANCE HISTORY

The secondary sodium pumps were first placed in service at the end of March, 1962, and the primary pumps at the beginning of April, 1962. Operating history of the pumps is shown in Table II.

TABLE II
OPERATING TIME AT VARIOUS TEMPERATURES
HNPF SODIUM PUMPS

Temperature Range	Operating Time (hrs)
300 - 500 F	~ 5000
500 - 700 F	~ 2000
700 - 900 F	~ 210
900 - 1000 F	~ 810

It can be seen that considerable time has now been logged in the design temperature range of 900 - 1000 F. Adequate control of pump speed has been demonstrated at speeds as low as 40 rpm (approximately 5% of rated speed).

Since the pumps were first placed into operation in the spring of 1962, all six of the sodium pumps have been removed for maintenance and for minor modification at least once, although no primary sodium pump has had to be removed since the sodium has become radioactive. Table III lists chronologically the pump removals.

TABLE III
HNPF SODIUM PUMP REMOVAL

Date	Pump Removed	Reason
12/7/62	No. 1 Primary	Pump flooded with sodium
		Weep hole modification
2/5/63	No. 2 Secondary	Binding - Insufficient impeller clearance
3/19/63	No. 2 Primary	Weep hole modification
3/26/63	No. 3 Primary	Weep hole modification
6/12/63	No. 2 Secondary	Binding - Pump would not rotate freely
6/13/63	No. 1 Secondary	Binding - Pump would not rotate freely
6/15/63	No. 3 Secondary	Binding - Pump would not rotate freely

Essentially, the entire history of major sodium pump maintenance and modification at the HNPF is condensed in the preceding table. Amplification follows in the ensuing sections of this report.

IV. PRIMARY SODIUM PUMPS

A. REMOVAL AND WASHING OF PRIMARY PUMP NO. 1

Primary pump No. 1 was the first of the pumps to be removed (December, 1962). The pump had become flooded with sodium following a tube leak in the No. 1 intermediate heat exchanger. Sodium was inadvertently forced into the primary loop during the secondary system draining operation.

The method used to remove the pump from the casing was as follows:

- 1) A plastic tube approximately 60 in. in diameter and 25 ft long was prepared from a 0.006 in. polyethylene sheet. Masking tape was used to connect the individual plastic pieces and to seal the plastic tube to the pump casing flange.

- 2) After unbolting, the pump inner assembly was raised into the plastic bag using the building crane. A dynamometer was used to measure the force exerted during the removal operation to prevent damage to the pump internals in the event of binding or mechanical interferences. An argon purge was maintained within the plastic bag during this operation, to minimize oxidation of the residual sodium on the pump and to prevent oxygen from entering the system.
- 3) After the pump inner assembly had cleared the casing flange the plastic bag was tied in two places and cut between the ties to seal the pump within the bag and also seal off the open pump casing.

The preceding method was subsequently used for the remaining six pump removals. Figure 2 shows secondary pump No. 3 after removal on 6/15/63. Note that the clear plastic permits some pump inspection prior to washing, and that sodium has drained fairly well from the pump parts.

After the pump was removed from the wash cell, a blind flange was used to seal the pump casing, and the pump placed in the pump wash cell (a facility supplied as part of the reactor plant and located in the reactor building within reach of the building crane). On this first occasion, the time required for washing was not known; therefore, steam at a pressure of 5 psig was admitted to the pump wash cell at a flow rate of 375 lb/hr for a period of 24 hours. Upon removal from the wash cell, the pump was found to be clean except for the annulus around the pump shaft, which was subsequently cleaned with a steam lance.

B. PRIMARY PUMPS MODIFICATION

Since primary pump No. 1 had already been removed from the system, it was decided to modify the pump impeller to correct a problem of sodium level control within the pump casing. It had been discovered that with the pump operating at 60 to 100% of design flow, but at a head lower than the design value of 160 ft at 7200 gpm, a low sodium level existed within the pump casing. Specifically, it was found by throttling tests that a pump low level alarm was actuated when the pressure differential across the pump dropped below 38.2 psig, at a sodium flow rate of approximately 90% of full flow. With all fuel channel orifices

wide open, it was determined that the total system drop was 11.5 psig at a pump speed of 400 rpm and a sodium flow rate of 58.2% of design. With the orifices in this position, primary pump No. 1 could not be increased above 475 rpm without causing a low level alarm. For the No. 2 primary pump the critical speed was 450 rpm and for the No. 3 primary pump, 500 rpm. The 11.5 psig pressure drop at 58.2% flow extrapolated to 31.7 psig at 100% flow, well below the 38.2 psig minimum pressure drop required to maintain pump casing sodium level.

Hydraulic analysis of the internal circulation paths within the pumps verified that, at the higher pump speeds; it was possible for more sodium to be pumped through the eight 1-1/4 in. diameter weep holes, from the discharge side of the impeller to the suction, than from the discharge of the pump through the various flow paths into the pump casing. These flow paths can be seen on Figure 1 and are: (a) across the case seal between the inner barrel and the outer case; (b) from the discharge of the impeller through the hydrostatic bearing; and (c) from the discharge of the pump across the upper wear ring of the impeller.

Several possibilities were considered to overcome the ~500 rpm restriction on pump speed. They were:

- 1) Throttling of Orifices on the Fuel Elements. Satisfactory operation of the pumps could have been accomplished by throttling to produce a pressure drop of 21.0 psig across the core at design flow. However, a pressure drop of only 8.5 psig was required to maintain fuel element outlet temperatures in the desired range. The remaining 12.5 psig pressure drop would have been purely parasitic.
- 2) Throttling with Throttle Valves. A similar increase in system pressure drop could have been established by partially closing the primary throttle valves. The additional pressure drop would also be parasitic.
- 3) Impeller Weep Hole Modification. The pump manufacturer recommended closing four of the eight weep holes to restore the hydraulic characteristics necessary for a net flow of sodium into, rather than out of, the pump casing.

The last of the three alternatives was implemented for the No. 1 primary pump, and the pump reinstalled. Subsequent testing of the pump verified that the pump could be run to full speed with no indication of low casing sodium level.

Primary pumps No. 2 and No. 3 were removed later at a convenient point in the startup program. Essentially the same procedure was followed for removal and steam cleaning, except that there was no need for follow-up steam cleaning.

V. SECONDARY SODIUM PUMPS

A. BINDING PROBLEMS

During the initial rise-to-power (February 5, 1963), when system temperatures were increased to design levels, secondary pump No. 2 began emitting rubbing sounds. Subsequently, the pump was shut down and removed for inspection. It was found that the thrust bearing was not properly shimmed to establish the required impeller axial clearance. At the elevated operating temperature there was sufficient differential expansion between the shaft and inner ballel to cause the impeller to rub against the diffuser.

From March 1963, to June 1963, the sodium pumps were operated to meet the requirements of the reactor startup program. These requirements were a steadily increasing system temperature and steadily increasing sodium flows.

Evidence of further binding of the secondary sodium pumps came to light on June 9, 1963. On that date, the reactor was scrammed due to an imbalance in flow between primary and secondary loops No. 2. About four hours after the scram, when restart had progressed to the point where the pumps were to be started, it was found that secondary pump No. 2 would not start with a 25 amp (excessive) current to the motor. Investigation showed that the pump was binding; the pump shaft, which normally turns freely by hand, could not be so turned.

The occurrence of binding in the No. 2 secondary pump led to a check of all other sodium pumps. It was found that secondary pump No. 1 also could not be rotated by hand, although it had been running under power from the motor. Secondary pump No. 1 and No. 2 were taken out of service, and about 12 hours

after the scram the three primary pumps and the remaining secondary pump (No. 3) were restarted. Although all pumps had been turned by hand prior to restart, it was now found that secondary pump No. 3 would not increase in speed. The pump was shut down and it was then found that manual rotation could not be effected.

B. REMOVAL AND INSPECTION

All three secondary pumps were removed (using the previously described removal procedure) and steam cleaned in the pump wash cell. Following is a summary of what was found upon disassembly of the pumps.

1. Secondary Pump No. 1

- a) The impeller lower wear ring showed no evidence of rubbing or the presence of foreign material.
- b) The impeller upper wear ring showed no evidence of rubbing or the presence of foreign material.
- c) Two deposits of foreign material were found on pads in the pressurized bearing. The largest piece, approximately 5/16 in. wide x 4 in. long, was located near the upper end of the bearing housing in a southwesterly direction. Figure 3 is a photograph of the material as found. The other deposit was located directly opposite on the lower end of the bearing and was about 3 in. long. The thickness of these deposits was approximately 0.010 in., which is equivalent to the annular clearance between the bearing and the journal.
- d) The mating surface for the impeller upper wear ring showed marking all the way around. These marks were not deep enough to measure and there was no evidence of shaft runout at this point.
- e) Burnishing of the journal of the pressurized bearing was observed; 4 in. at the top end and 3 in. at the bottom (Figure 4).

2. Secondary Pump No. 2

- a) The grooves on the impeller upper wear ring showed the presence of dispersed foreign matter; the peaks were flattened. Figure 5 shows some of this foreign material.
- b) The impeller lower wear ring was also damaged and the presence of foreign material in the grooves was observed. Flattening of the tops of the threads was noticed over an area 180 degrees from a region of similar damage on the upper wear ring. The corresponding surface in the diffuser showed wear in the southeast region.

- c) Burnishing of the journal of the pressurized bearing was observed as follows: 4 in. at the bottom end, 2 in. at the top end and a 1 in. band near the center. The upper end also showed evidence of scoring.

Random deposits of foreign material were observed in the bearing housing. The axial spacing of these deposits corresponded to the bands appearing on the bearing journal. The thickness of these deposits varied up to a maximum of 0.015 inches.

3. Secondary Pump No. 3

- a) The impeller lower wear ring showed no evidence of wear or rubbing, nor presence of foreign matter.
- b) No markings appeared on the journal or housing of the pressurized bearing.
- c) A deposit of foreign metallic material 1/2 in. wide x 3/4 in. long was impressed on the lower portion of the upper wear ring surface. Additional bits of material were observed to be scattered over the rest of the wear ring surface. The mating surface was severely scored.

All three pump inner barrels showed the presence of a protective covering (paint) which had coked as a result of the high temperature on the lower portion of the pump inner barrel. Distribution of the coked material roughly followed the temperature distribution around the inner barrel, as shown in Figure 6.

C. CAUSE OF DAMAGE

It is evident that the apparent simultaneous binding of all three secondary sodium pumps demands some explanation. That the binding was caused by introduction of extraneous material into the close clearances within the pump seems fairly obvious, in view of the fact that the pumps rotated freely after the extraneous material was removed and the pump reassembled.

The coincidental failure of the three secondary pumps may have been more apparent than real. Had not a reactor shutdown occurred, focusing attention on binding of the pumps, operation of the pumps might have continued until the binding became extremely pronounced.

There was considerable investigation into the possibility of warpage or deflection of the outer pump casing as a result of uneven temperature distribution of the case. Cooling fins are installed on the pump casing to reduce the temperature from 400 F to approximately 150 F in the axial direction. Thermocouples installed on the pump casing revealed that the temperature distribution radially around the pump casing was far from uniform, as illustrated in Figure 7. On the west side of the outer casing of secondary pump No. 2, the temperature difference between the lower end of the cooling fins and the upper end of the cooling fins was about 235 F, whereas the corresponding temperature difference on the east side was about 90 F, indicating excessive cooling on the east side relative to the west side. As a result of the temperature distribution shown, it would be expected that the entire outer casing would deflect toward the east about .03 inches at the lower end of the casing, causing some misalignment of the pump internals. The amount of internal misalignment is small under these conditions, but not negligible. However, this amount of misalignment has been calculated to be insufficient to cause seizure of the pump shaft, neglecting any decrease in effective clearances as a result of accumulation of foreign material. It has, therefore, been tentatively concluded that the primary cause of the pump seizure was accumulation of foreign material in the pump clearances, and that a contributor to the seizure was the slight misalignment of pump internals caused by uneven temperature distribution in the pump outer casing.

D. CORRECTIVE ACTION

All extraneous material was removed from the pumps and the additional corrective action taken as described in the following.

1. No. 1 Secondary Pump

Diametral running clearances of the impeller upper and lower wear rings were increased from 0.039 in. to 0.054 in. and 0.065 in. to 0.094 in., respectively (maximum values). No material was removed from the journal of the pressurized bearings; the surface was merely polished and the radial clearances were left at 0.010 in. No clean-up of the wear ring stationary mating surfaces was required.

2. No. 2 Secondary Pump

Running clearances of the impeller upper and lower wear rings were increased to match the new dimensions given for pump No. 1. Measurements of casing displacement, inner barrel alignment fits and diffuser surface showed no distortions, so measurements of the corresponding parts of the other pumps were not deemed necessary.

3. No. 3 Secondary Pump

The running clearances of the impeller upper and lower wear rings were increased to match the new dimensions given for pump No. 1. Considerable polishing was required to clean the stationary mating surface for the impeller upper wear rings.

4. All Secondary Pumps

The paint on the outer surface of the inner barrels was removed by using paint remover with a subsequent acetone wash.

To correct the temperature distribution problem, a forced cooling system, consisting of a 500 scfm blower, ducting and distribution manifold was installed to blow air upward past the cooling fins. The resulting improvement in temperature distribution is shown in Figure 8.

Analysis of material found in No. 1 secondary pump indicated that it was of the same chemical composition as weld rod used in fabrication of steam generators. The material found in secondary pumps No. 2 and No. 3 contained iron, nickel, and chromium in approximately the proportions expected in stainless steel. Introduction of the foreign materials into the system undoubtedly occurred during initial fabrication of the system and subsequent modifications.

To minimize the probability of further pickup of foreign metallic particles in the pumps, 10 micron sintered metallic filters (formerly used in the melt stations for the plant) were installed to permit bypass filtration of the sodium in the secondary sodium system. The sodium in each of the three loops was passed through these filters approximately six times at linear velocities of about 10 feet per second.

All pumps were reworked as described above and reinstalled in a total elapsed time of 8 days. Since June 1963, when the pumps were returned to service, operation has been satisfactory.

VI. CONCLUSION

It can be said that performance of the six heat transfer system sodium pumps at the HNPF has been quite satisfactory. No problems inherent to the design have been encountered, except for the impeller modifications required to permit operation at less than design head conditions. All of the difficulties which required plant down time to allow corrective action were due to extraneous items. That is; foreign material, case flooding and improper assembly (secondary No. 2) were all items not related to mechanical design of the pumps.

Figure 1. Secondary Sodium Pump

Figure 2. HNPF Secondary Sodium Pump No. 3 (South Quad) Being
Removed to Wash Cell

Figure 3. Inside View of Secondary Pump No. 1 Pressurized Bearing
(Arrow points to foreign material deposits on bearing housing)

Figure 4. HNPF Secondary Sodium Pump No. 1 Bearing
Journal and Impeller East Side

Figure 5. HNPf Secondary Sodium Pump No. 2 Bearing Journal and Impeller
(Note deposits of extraneous material on upper wear ring)

Figure 6. HNPf Secondary Sodium Pump No. 2 Inner Barrel North View
Showing Temperature Distribution Pattern

Figure 7. Secondary Pump Casing Temperature Distribution (before modification)

Figure 8. Secondary Pump Casing Temperature Distribution
(after modification)