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CRBRP SODIUM CIRCULATING PUMP
DESIGN EVALUATION

F. MARRUJO - BJ

M. COOK - BJ

L. MANNERS - GE

H. COTHRAN - CRBRP/PO

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U.S. - ERDA/JAPANESE - PNC SEMINAR
A CRBR PUMP DESIGN CONCEPTS AND
RESULTANT DESIGN EVOLUTION

1. Primary Sodium Pump Description. One sodium pump is provided in the hot leg of each primary loop. Each of the pumps is nominally rated at 33,700 gpm ($2.12 \text{ m}^3/\text{sec}$), 458 ft (139.6m) total dynamic head. The pumps are driven by conventional squirrel-cage induction motors rated at 5,000 horsepower at 1116 rpm. A pony motor rated at 75 horsepower is coupled to each pump motor by a reduction gear and overrunning clutch to drive the pump system at about 7-1/2 percent speed during standby operation, refueling, and decay heat removal periods. Each pump drive motor is powered by a commercial motor-generator set with fluid coupling. Drive speed turndown ratio is 4:5:1.

The design of the sodium pumps is based on the free-surface centrifugal pump concept as successfully operated in EBR-II, EFBR, SRE, and HNPf. In this concept, the drive motor is located above the shield deck, the pump drive shaft penetrates the shield, and a buffer gas is contained between the sodium free surface and the final atmosphere seal at the pump shaft and containment boundary.

In the Fast Flux Test Facility (FFTF) and CRBRP systems, the Reactor vessel outlet plenum operates at essentially atmospheric pressure, and the primary pumps are located in the hot let of the heat transport system. The basic in-sodium component design elements, such as sodium-lubricated bearings, hydraulic design members, rotating shaft seals, material processes, and metallurgy, have been demonstrated by approximately a million hours of aggregate operation in the above-mentioned plants.

2. Evolution of Design Concept. The length of the primary pump was originally established by the requirement that the pump tank and the reactor vessel share a common cover gas system which maintained a pressure of about 10" W.G. over the free surfaces. The pump is required to retain the capability of circulation over a liquid level range of approximately 13' (4m). This range of liquid level when combined with the space requirement for radiation and thermal shielding and adequate submergence of the hydraulic components, resulted in a pump shaft length of approximately 28'-0" (8.5m). This concept was commonly referred to as the "long shaft" pump.

The current reference design (Figure 1) is based on the results of a task force study for a short shaft primary pump.

The task force study resulted in recommending "short-shaft" primary pumps for the Clinch River Breeder Reactor Plant, based partly on economic considerations, but concluded that "the overriding consideration in recommending a short shaft pump is that it is believed that a short shaft pump offers the higher probability of success in designing, manufacturing and operating the pumps."

The task force report reviewed four basic methods of liquid level control for the pump:

1. An overflow type pump with the liquid level determined by the elevation of the overflow nozzle.
2. An active cover gas pressure control concept with sodium level sensors which provide the signal of control of the gas pressure supply and relief valves.
3. A standpipe-bubbler system.
4. A standpipe-overflow concept which combines a trapped gas space ("diving-bell" concept) in the pump tank together with overflow leakage return to the pump suction.

As recommended by the task force report, the selected concept for liquid level control in the pump tank is the "Standpipe-Bubbler" System (3); the backup design is the active cover gas pressure control concept (2). The overflow type concepts (1 and 4) were not recommended by the task force.

The "short-shaft" concept shortens the pump about 8 feet by lowering the support elevation of the top end of the pump tank to approximately the same elevation as the normal operating sodium level in the reactor system. This arrangement retains the location of the pump hydraulic components below the minimum sodium level in order to maintain the capability of pump circulation, including starting and stopping, during minimum sodium level conditions.

In order to protect the pump shaft seal assembly from flooding by sodium in the event of loss of pump cover gas pressure, the seal is located at an elevation approximately 16 inches (40 cm) above the maximum sodium level in the reactor vessel.

This approach resulted in the development of the "Standpipe-Bubbler" pump tank liquid level control system which establishes and controls the liquid level in the pump tank about 8 feet (2.4 m) below the normal reactor sodium level in order to maintain the desired thermal gradient in the biological shield and the pump support structure.

3. Level Control System for CRBRP Primary Pump. The pump described in the specification is a free-surface, modified sump type pump, arranged as shown in Figure 1. The design of the pump is based on the concept for sodium level control using the "standpipe-bubbler" system in which a continuous flow of inert gas is supplied to the pump cover gas space. During all static and normal operating conditions, the gas supply pressure will be sufficient to depress the liquid sodium level to the standpipe nozzle elevation and the gas will bubble up the standpipe to the reactor cover gas system.

The standpipe is essentially one leg of a manometer which automatically balances the gas pressure in the pump tank with the pressure in the reactor and suction piping system. This system provides a simple method of pump tank cover gas pressure control compared to an active cover gas system. The standpipe-bubbler automatically performs the function of a pump cover gas vent and relief valve to the cover gas system, and does not rely on the signal of a liquid level sensor for level control.

The gas blanket in the pump tank serves as a damper on level swings, during pump trip, for example, when the sodium drawdown level at 100% flow would tend to rise to the normal system level. During this event the gas will compress to a level somewhat above the gas-bubbler nozzle, depending on the geometry and volume of the gas space. As the gas supply continues to enter the pump tank, the liquid level will fall until the bubbling action through the standpipe is re-initiated.

A development program in support of the standpipe bubbler concept was completed with the preparation of a computer program suitable for inclusion in the reactor system model. The standpipe bubbler analytic model was verified by an experimental water model operated in the Borg Warner Research Laboratories. It is planned to test the full size standpipe bubbler system during water tests with the prototype pump.

4. Design Problems and Resolution. The sodium pump designs for CRBRP must provide for thirty years of operation at various plant operating conditions, continuous operating capability for reactor heat removal under normal, upset, and emergency conditions, including thermal transient conditions and seismic events, accessibility for service including in-service inspection as required by ASME Code, and satisfactory design analysis in accordance with the ASME Code.

The design layout drawing for the CRBRP pumps (Figure 1) has been approved for detail design purposes. Completed preliminary static, dynamic, and stress analyses of the design established a feasible configuration of shaft, supporting structure, and pump tank. The hydraulic design was based on performance of a commercial double suction pump of similar configuration.

A) Stress Analysis

Stress problems were discovered during detail design of the original pump volute case as shown in Figure II-1, which placed in doubt the stability of this structure during thermal transients. It was decided to change the pump case design to the configuration shown in Figure II-2, which, because of its greater symmetry and exposure to two-sided thermal shock, is expected to be more stable under thermal transients. Structural analysis of this revised design is continuing and work has been initiated on the patterns to make the required castings. Inspection of Figure II-2 shows that it differs from the former design in that the inlet flow passes around the inside of the tank and sweeps over the entire outer surface of the pump case.

B) Dynamics Analysis

A global analytic model which comprises the pump, drive motor, foundation and piping has been prepared and used to study the dynamic and seismic response of the pump. By means of parametric studies with this model, it has been possible to produce a design in which the first natural frequency is above the shaft operating speed. Analysis of this design shows that seismic induced stresses will be relatively low.

C) Mechanical Design

The reference design is a double suction impeller with a triple volute pump case and a dual sodium bearing configuration to provide support to both sides of the impeller.

Principal considerations which led to the selection of the dual bearing were:

1. Reduction in size, weight, and diameter of the pump shaft which enhances the producibility and reliability of the pump under high-temperature service.
2. Improved structural and hydraulic symmetry in the pump case.
3. Reduced diameter and leakage flow losses in the sodium bearings.
4. More confidence in the pump dynamic behavior.

5. Model Testing. Because thermal transient design considerations have changed the configuration of the flow passages into the impeller it was decided that a test of the suction side flow distribution would be prudent. A one quarter size air flow test model has been constructed and operated with which it has been possible to obtain flow velocity measurements at the various inlet parts to the impeller. The data obtained from this test have provided an added measure of confidence in the pump suction configuration.

6. Test Plans.

A) Water Testing. A half-scale model of the pump has been fabricated and tested in water. In general, the hydraulic scale model confirmed the predicted performance, except that net positive suction head required at the runout flow rate was greater than expected. Tests were performed to determine what inlet vane modifications were needed to improve the performance. A second series of half-scale model tests has been performed to evaluate proposed prototype pump instrumentation and to further evaluate the operation at pony motor speed.

B) Sodium Testing. To accommodate testing of the Clinch River Prototype Pump, the SPTF is to be modified to extend the present flow capability of 24,000 gpm to 39,100 gpm.

The changes to be made to the SPTF will provide thermal transient simulations of 400°F positive, and somewhere between 400°F to 500°F negative. This range agrees very closely with the predicted "Upset" transients which are part of the design basis for the Clinch River Plant. The SPTF capability of applying a transient rate of $\pm 4^{\circ}\text{F}/\text{sec}$ exceeds the rate of application of any CRBRP upset transients. If the pump maintains its integrity through the application of these "Upset" transients and meets performance requirements, it can be considered to be qualified.

- C) Shaft Seal Tests. A seal component test rig has been put into operation to perform development tests of the shaft seal sealing rings and of the internal screw pump which circulates cooling oil in the seal cavity. An assembled prototype seal unit will combine the seal rings and circulating pump developed in the component test program with the oil cooler into a complete seal package which will then be operated to verify the final design. Results to date indicate that expected seal life may significantly exceed the specified value.

7. Fabrication Status. Purchase orders have been placed for all long-lead material such as plate, forgings and castings. Fabrication contracts have been placed for the pump tank, inner structure assembly and other major parts.

There are no known problems at this time which are expected to cause delay in the program.

CRBRP PUMP

Figure 1

FIGURE II-1

FIGURE II-2

CRBRP PROTOTYPE PUMP

• ISOMETRICS

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NOTE: ISOMETRIC DRAWINGS ARE
BASED ON 1E3862 REV "A"
AND ARE PROVIDED AS A CON-
VENIENCE ONLY. THEY ARE NOT
INTENDED TO BE INTERPRETED
AS DEFINING DESIGN CHARACTER-
ISTICS.

MOUNTING FLANGE
• FORGING #312750

CYLINDER
• PLATE #312769

S.P.D. NOZZLE
• FORGING #312771

CONE
• PLATE #312769

TRANSITION RING
• FORGING #312761

SUCTION NOZZLE
• FORGING #312757

Φ SUCTION

PUMP TANK

• PART NUMBER 409064
• ESTIMATED WEIGHT 44,000 LBS.

FORMED BAND
• FORGING #312777

FORMED BAND
• FORGING #312776

DISHED HEAD
• FORGED #312762

DRAIN NOZZLE
• FORGING #312772

SEALING CONE
• PLATE #312769

GUDGEON (3)
• FORGING #312761

GUDGEON SLAVE (2)
• FORGING #223976

DISCHARGE NOZZLE
• FORGING #312756

DISCHARGE Φ

1

THERMAL SHIELD
• PART NUMBER T.B.D.
• ESTIMATED WEIGHT - 4,800 LBS.

LOWER
INNER STRUCTURE
 PART NUMBER 429273
 ESTIMATED WEIGHT - 10,200 LBS.

HYDRAULIC
ASSEMBLY
• PART NUMBER T.B.R.
• ESTIMATED WEIGHT 2000 LBS

ROTATING ASSEMBLY

• PART NUMBER 409074
• ESTIMATED WEIGHT 6000 LBS.

7

PUMP
INTERNALS

ESTIMATED WEIGHT:
LBS.