DESIGN OF PFBR SODIUM PUMPS AND THEIR CAVITATION PERFORMANCE CRITERIA

R.D.Kale and A.S.L.K.Rao

Reactor Research Centre, Kalpakkam, Tamilnadu 603 102, India

1.0 INTRODUCTION

The Prototype Fast Breeder Reactor (PFBR) currently under design in India is a 500 MWe sodium cooled reactor plant of pool design (Fig.1). The reactor will have four heat transport loops in the primary as well as the secondary. The total primary coolant flow is expected to be 32000 cubic metres/hr and the total pressure drop in the circuit within 80 mlc. Primary sodium will be circulated by four pumps immersed in the cold sodium pool (400°C) and supported from the roof structure. This paper discusses the design of the primary sodium pumps with particular reference to cavitation performance requirements. An outline of the experimental programme for the hydraulic development is also given.

2.0 DESCRIPTION AND DESIGN OBJECTIVES OF PRIMARY PUMPS

The pump concept selected is a vertical, single stage, bottom suction centrifugal free liquid surface pump with a bottom sodium lubricated hydrostatic bearing and top antifriction thrust bearings. The shaft sealing is achieved by means of a double mechanical seal which isolates radioactive cover gas and sodium vapour from reactor building air. The pump is driven by an electric motor connected through a flexible coupling and the motor speed can be varied smoothly over a wide range. The principal material of construction of the pump is type 304 stainless steel. The enclosed figure shows the proposed pump arrangement in the primary circuit.

The following are the main characteristics of the primary pumps:

Design capacity	: 8050 cubic metres/hr
Design head	: 80 mlc
Speed	: 700 rpm (maximum)
Power	: 2000 KW (approx.)
NPSH available	: 13.5 mlc
Design temperature	: 400°C

2.1 Design objectives:

The following are the main objectives of the pump hydraulic design:

1) The design should permit safe operation of the pumps with low NPSH available in the primary circuit (See (3) below)
2) The pump design should yield a high overall efficiency, above 75%
3) The overall size of the hydraulics i.e. the maximum diameter of the diffuser casing, should not exceed 2000 mm
4) The head capacity curve should be stable to permit parallel operation of the pumps
5) The mechanical design of the pump should provide high reliability in service

3.0 CAVITATION CRITERIA

The need to design the pump to operate smoothly at a low net positive suction head (NPSHA) arises because of low cover gas pressure (preferred from consideration of sealing) and limited submergence in the pool sodium (to have a shorter shaft-higher critical speed). The operation of the primary pump must be free from cavitation in order to (a) ensure prolonged service life (25-30 years) of the hydraulic parts by limiting cavitation-erosion damage and (b) limit the noise emitted by the equipment facilitating acoustic detection of sodium boiling inside the reactor core. It is found that the margin adopted over the required NPSH by different sodium pump designers are quite different varying from about 30 to 100% i.e. NPSHA/NPSHR = 1.3 to 2.0

Where NPSHA - available NPSH in the circuit and

NPSHR - refers to the value corresponding to 3% drop in pump performance.

However, recent information indicates that the cavitation damage can take place (and more particularly in sodium compared to that found in water tests) even at an NPSH value for which there is no degradation of the hydraulic performance. Further it is now known that noise emission from the pump can take place at NPSH values which are considerably higher than that (NPSHR) corresponding to drop in hydraulic performance. With this backgrounbd, we have presently specified a cavitation criterion which requires that there shall be NO indication of visible cavitation during water test at the operating NPSHA. This obje ctive will have to be attained through model and prototype testing in water.

4.0 HYDRAULIC DESIGN FEATURES TO SATISFY CAVITATION CRITERION

4.1 A bottom suction impeller is choosen wherein sodium enters straight into the eye of the impeller without turning and hence the hydraulic losses are minimised. Also, the submergence available at the impeller eye is more. The concept thus gives higher available

NPSH. Further, as the shaft is not passed upto the eye, the eye area is large reducing NPSH required.

4.2 The speed of the pump was selected to give an operating suction specific speed (SNA) equal to 155 in metric units

$$SNA = \frac{N\sqrt{Q+QL}}{60\,(NPSHA)^{3/4}}$$

SNA = 155; Q = 8050 cubic metres/hr; QL=165 cubicmetres/hr

NPSHA= 14 mlc gives N=700 rpm

4.3 A parametric study was carried out to find the optimum values of design parameters viz.

a) Covergas pressure,Po (b)impeller degree of prerotation at inlet R1 (c) number of impeller vanes,Z and (d) the impeller inlet vane angle, B1 that give good NPSH margin (NPSHA/NPSHR) without sacrificing much on sizing and efficiency.

a) Covergas pressure:(Po) An increase in the covergas pressure allows the pump to be designed at higher speeds for the same NPSH margin and results in reduced sizing and improved efficiency of the hydraulic parts (or a higher NPSH margin for the same speed). It is difficut to maintain higher pressures without complicating the design of seals in the reactor closure. The reference pump design was carried out with a covergas pressure of 50 millibars (gauge) keeping the option open for higher pressures.

b) Degree of Prerotation R1: is defined as the ratio of shockless capacity to the rated capacity and is given by $R1 = \frac{U1 \cdot \tan B1}{VR1}$

Where U1 = Peripheral velocity of impeller at inlet

B1 = Impeller vane inlet angle

VR1= Radial component of absolute velocity of fluid at impeller inlet

From the parametric study, it was observed that a higher degree of prerotation (1.4 to 1.8) yields low NPSH requiremens, but at the expense of both increase in size and reduction in efficiency.

c) Vane inlet angle B1: Smaller vane angles were found to give better cavitation margin with minimum loss in sizing and efficiency. For PFBR pumps, B1 = 15° is thus chosen.

d) Number of vanes Z: Fewer vanes were found to be useful in reducing NPSHR but resulted in increase in pump sizing because of poor guidance and low vane effectiveness. Reduction in efficiency was however not significant.

The hydraulic design presently being pursued has the following characteristics.

N = Rated speed = 700 rpm

Po = Covergas pressure = 50 millibars (gauge)

R1 = Degree of prerotation = 1.4

B1 = Vane inlet angle = 15°

Z = Number of vanes = 6

NPSH Available = 13.5 mlc

NPSHA/NPSHR = 1.3

Max. size of the hydraulics = 1775 mm

Overall efficiency = 74%

5.0 OUTLINE OF EXPERIMENTAL PROGRAMMÉ FOR HYDRAULIC DEVELOPMENT

To attain the various objectives of the pump hydraulic design an experimental programme is planned to cover the following:

1) Hydraulic studies on small model impellers to arrive at the design objectives globally.

2) Hydraulic studies using 1/2 scale model of the impeller and casings with due regard to intake conditions in order to precise the design w.r.t. cavitation requirements.

3) Full scale testing of the pump in water

It is planned to use both visual as well as acoustic methods to detect onset of cavitation during the various phases of hydraulic studies. This will enable us to correlate the results from acoustic measurements and visual tests so that acoustic means, the only means that can be deployed during pump operation in sodium can be later used to determine the state of impeller performance either during sodium tests (commissioning stage) or during reactor operation.

6.0 CONCLUSIONS

This paper has attempted to provide the Indian position on the status of sodium pump design with particular reference to cavitation performance.

A more rational basis for cavitation criterion is necessary and this will be possible only after further progress is achieved in understanding effects of cavitation damage when operating with a small degree of cavitation.

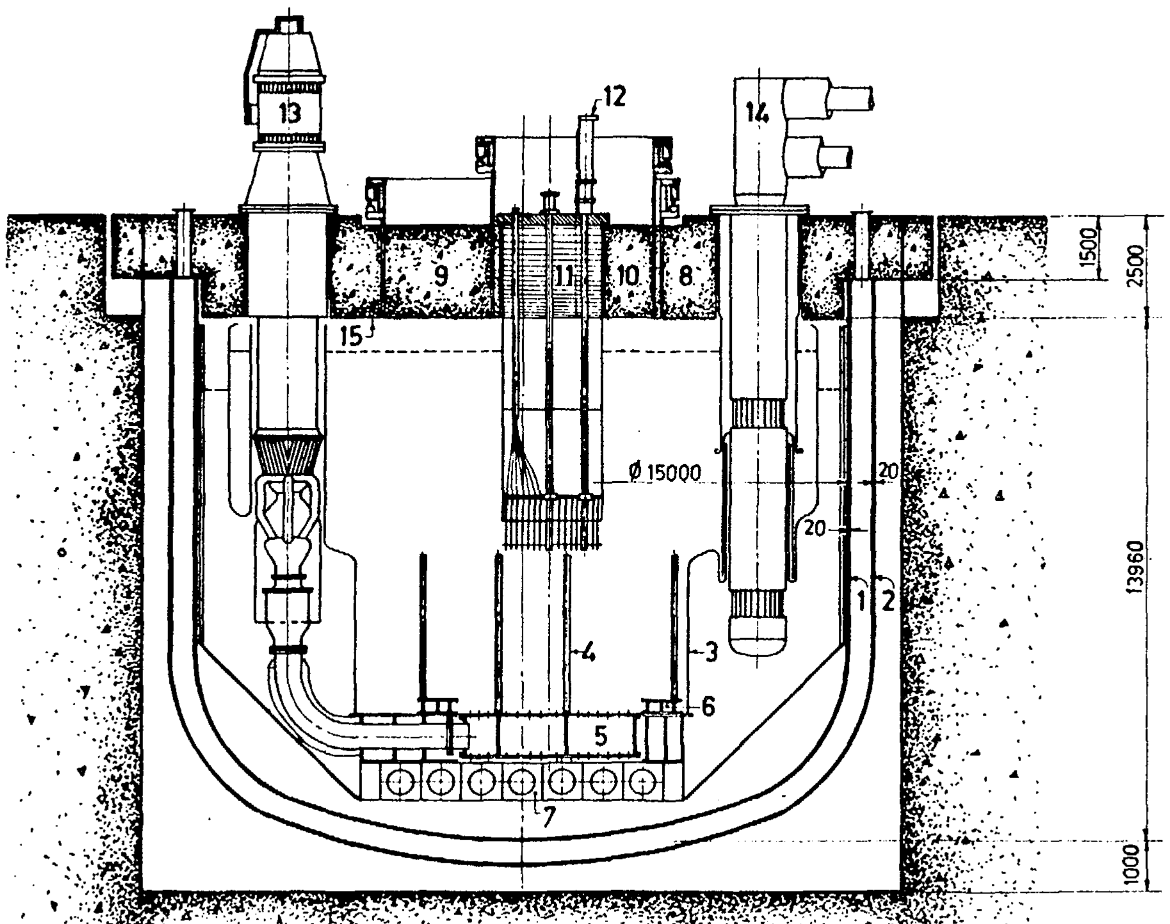
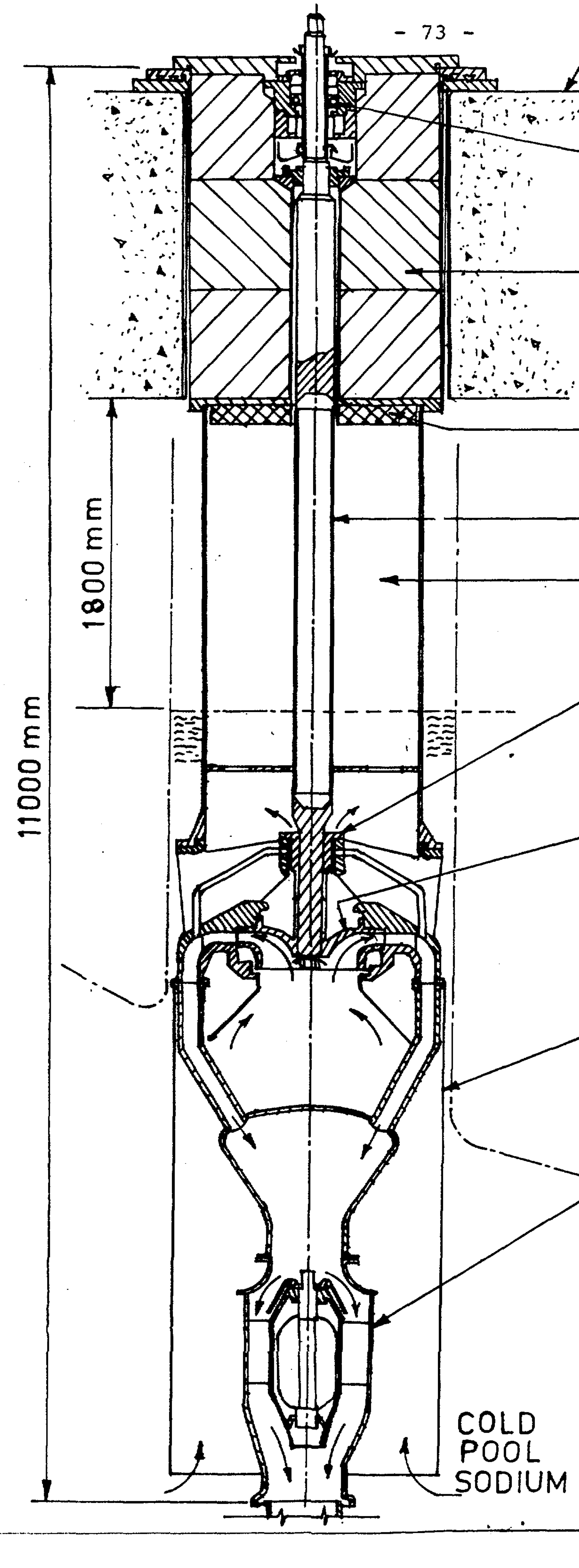


FIG.1
REACTOR ASSEMBLY

1. MAIN VESSEL
2. DOUBLE ENVELOPE
3. INNER VESSEL
4. CORE SUB-ASSEMBLIES
5. GRID PLATE
6. AUXILIARY GRID PLATE
7. CORE SUPPORT STRUCTURE
8. ROOF SLAB
9. LARGE ROTATABLE PLUG
10. SMALL ROTATABLE PLUG
11. CONTROL PLUG
12. CONTROL ROD DRIVE MECHANISM
13. PUMP
14. I.H.X
15. THERMAL INSULATION



CAPACITY — 8000 M^3/h
HEAD — 80 mlc.
POWER — 2000Kw

PRIMARY SODIUM PUMP FOR PFBR