

DESIGN IMPROVEMENTS IN THE ELECTROMAGNETIC PUMPS USED IN SODIUM SYSTEMS OF INDIAN FAST BREEDER REACTORS

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INTRODUCTION:

Reflux type Annular Linear Induction Pumps (ALIPs) are employed for circulating large quantities of liquid sodium in the auxiliary circuits of Indian sodium-cooled fast breeder reactors. A pump design like this allows replacement of the winding assembly without disturbing the sodium duct assembly. This is a key advantage of this configuration that also allows simplification of upkeep and maintenance. Drawing on operational experience from multiple sodium loops, efforts have been made to enhance the availability and performance of ALIPs for future FBRs. Several design refinements and additional features have been incorporated into the sodium duct assembly, some of which are summarized as part of this paper.

1. OVERVIEW

Indian sodium cooled fast breeder reactors employ the reflux type Annular Linear Induction Pumps (ALIP) for pumping large quantity of sodium in auxiliary circuits [1, 2]. The cross section of a typical reflux type ALIP for flow capacity of 170 m³/h is shown in FIG. 1.

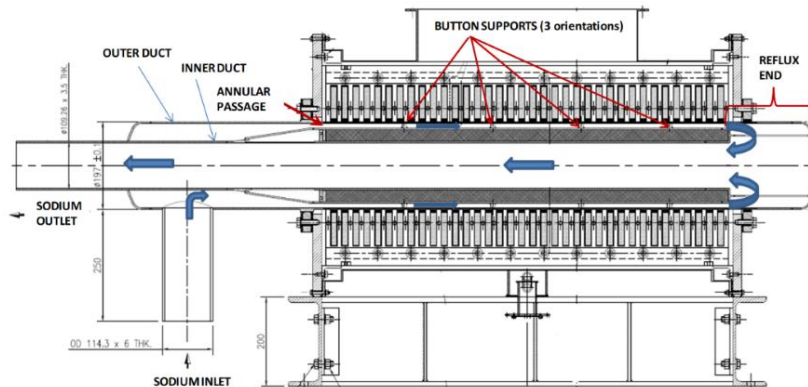


FIG.1. Schematic of a typical ALIP for a reflux type sodium cooled fast reactors [1]

The entry to the annular passage of an ALIP, receives sodium from single radial nozzle and passes into a transition region (inlet plenum) between the inner and outer ducts. This leads to significant flow mal-distribution at the inlet of the annular portion. The pumping action in the form of electromagnetic forces (Lorentz force) arising out of interaction between a traveling magnetic field and induced current in liquid sodium primarily occurs within the narrow annular portion. Multiple reflux type Annular Linear Induction Pumps (ALIPs) are employed for circulating large quantities of sodium in the auxiliary circuits of Indian sodium-cooled fast breeder reactors. Drawing on operational experience, various design refinements have been implemented with respect to the sodium duct assembly of ALIPs improving their availability and overall performance. The effectiveness of the design provisions has been extensively assessed through water loop experiments. The same is further confirmed with the help of sodium loop tests. Following validation, the design has been incorporated into multiple sodium loops of FBRs and has demonstrated satisfactory performance. The details of the design improvements are discussed in the following sections.

2. DESIGN OF REFLUX END DUCT ASSEMBLY:

The sodium duct assembly is fabricated from SS304LN stainless steel. In the initial design (“original” in Fig. 2), the inner duct is joined to the outer duct by an intermediate shell incorporating cutouts, as shown in Figs. 1 and 2. This shell is welded to the inner duct at one end and to the dome of the reflux head of the outer duct at the other. The cutouts serve as the flow path for the sodium turning within the reflux head and entering inner duct from the concentric annulus within the outer duct. The configuration performs satisfactorily under steady-state operating conditions. However, during certain thermal transients, temperature differences arise between the inner and outer ducts, causing a mismatch in their thermal expansions. This induces cyclic stresses in the connecting shell, which subject it to fatigue loading and consequently limit the service life of the inner duct assembly.

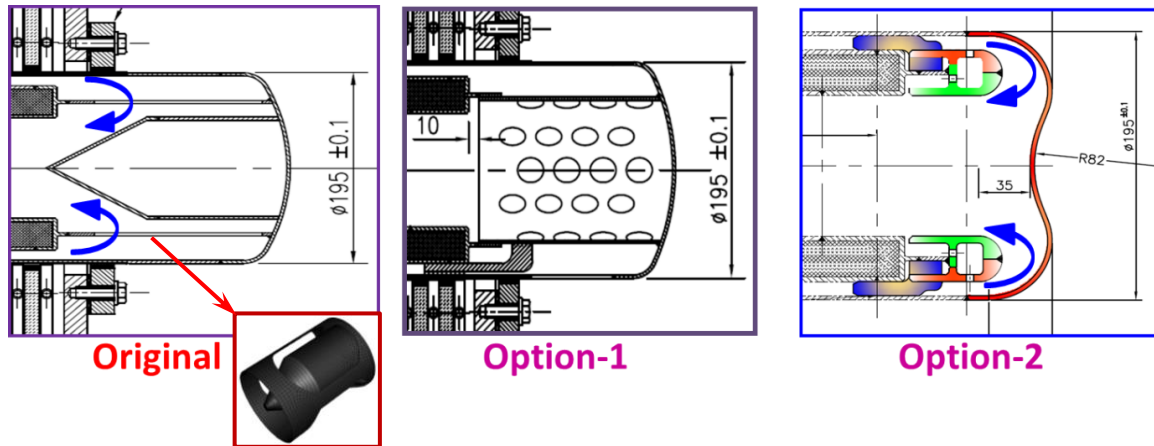


FIG.2. Initial and modified designs of Reflux end duct assembly

As a design improvement, a porous shell with a sliding joint has been proposed (Fig. 2, Option-1). This configuration eliminates thermal stresses and thereby enhances the design life of the assembly. A 10-mm clearance, as indicated in Fig. 2, is incorporated to accommodate the maximum differential thermal expansion expected during the most severe transients in the sodium loop. The required porosity of the shell is achieved through circular perforations of 24-mm diameter, selected to minimize the risk of blockage at lower temperatures due to sodium solidification in the presence of impurities. In addition, this configuration reduces the pressure drop by approximately 3.5 kPa as compared with the initial design, primarily owing to the reduction in flow recirculation.

As a further design enhancement, additional CFD analyses are conducted to further eliminate recirculation zones, leading to the development of Option-2 [3]. In this configuration, the interconnecting porous shell is completely removed. Instead, the termination of the inner shell is provided with a smooth turn profile, while the dished end is modified to prevent the formation of dead or recirculation zones in the reflux flow path. The configuration has been established following multiple CFD studies specifically aimed at eliminating stagnant regions and thereby minimizing pressure losses. With the Option-2 design, the pressure drop is further reduced by approximately 12 kPa compared with Option-1. In view of this, Option-2 is recommended for the auxiliary circuit of future fast breeder reactors (FBRs).

3. DESIGN OF ANNULAR SPACER SUPPORT:

The initial design of the inner duct incorporated four equally spaced intermediate button supports, as shown in Fig. 1, to guide the inner duct packed with core laminations. During pump operation, the measured vibration level was approximately 3 mm/s, which is within the acceptable limit of 5 mm/s. Nevertheless, to ensure safe long-term operation, design modifications are undertaken to further reduce vibration. The existing four intermediate pads are supplemented with additional support pads to minimize local fretting wear against the outer duct. Furthermore, both ends

of the inner core are fitted with additional guide pads of tighter clearance to improve positional stability. To avoid wear between the SS304LN guide pads and the outer duct of the same material, and to prevent self-welding under contact, a Colmonoy coating has been applied to the end pads. The modified configuration is illustrated in Fig. 3.

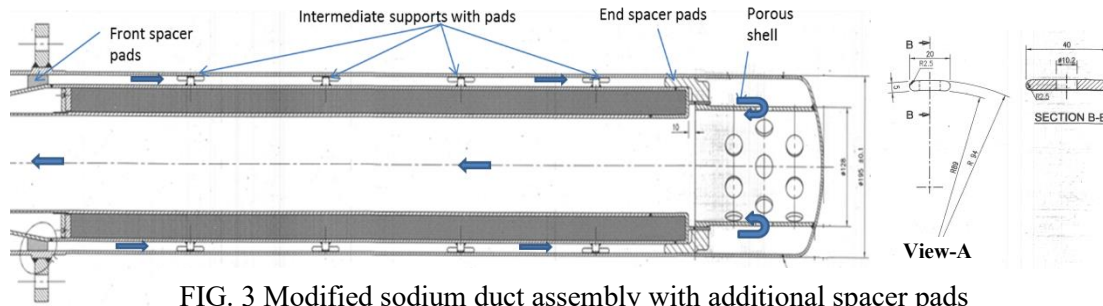


FIG. 3 Modified sodium duct assembly with additional spacer pads

The modified design has been tested in a sodium loop and has demonstrated improved performance, with vibration levels reduced to below 1.5 mm/s. Based on these results, the same configuration was implemented in the actual pump, where stable operation with minimal vibration was achieved as well.

4. FLOW REDISTRIBUTION DEVICE AT ENTRY:

Any flow mal-distribution at entry to annular passage of ALIP can lead to onset of magneto-hydrodynamic instability [4] which needs to be avoided for all plant conditions. In order to achieve a circumferentially uniform velocity at entry, a porous plate with variable (sector wise distributed) porosity is conceived and devised. the porosity distribution is translated into a porous plate design that can be manufactured and installed. The required porosity distribution is achieved with the help of circular holes distributed in the wall of frustum of cone appropriately sized and spaced so as to closely respect the derived porosity distribution. The porous plate positioned in ALIP annular entry is shown in Fig. 4.

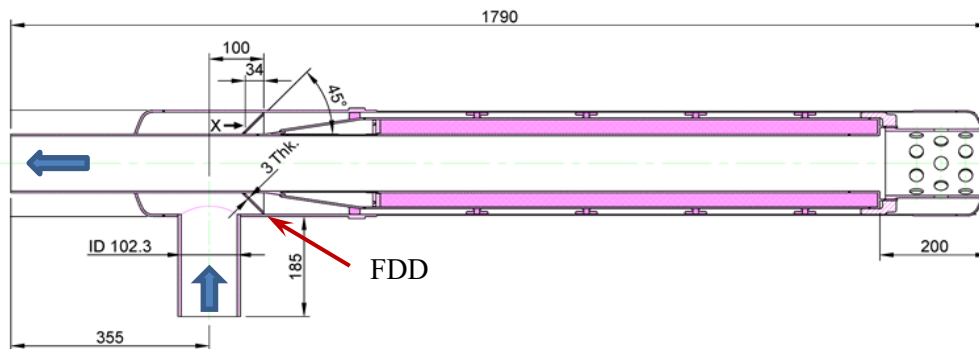


FIG.4: ALIP with Flow Distribution Device (FDD) at suction to annular path

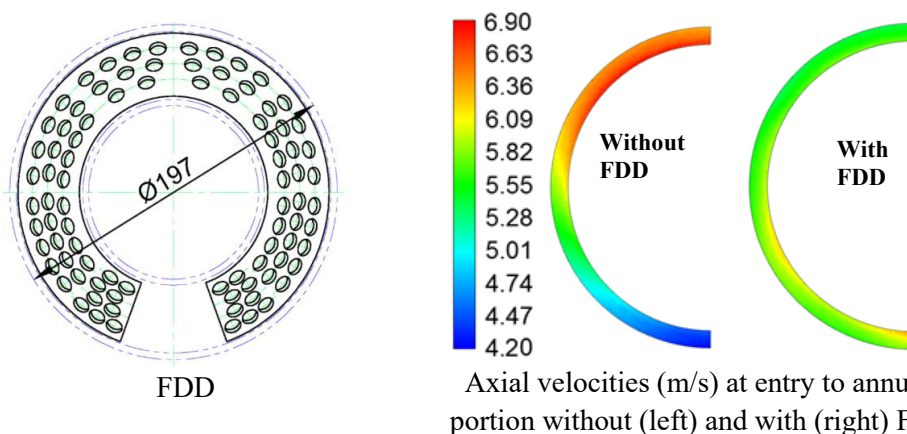


FIG.5. Comparison of flow redistribution at annular plenum of ALIP without and with FDD

With the FDD addition, the difference between maximum and minimum velocities (circumferential variation of radially averaged velocities) reduces from 2.4 m/s to 0.3 m/s. The hydraulic pressure drop of the ALIP increases by 8 kPa which is insignificant as compared with developed head of 400 kPa. However, decrease in NPSHA of the pump is insignificant due to the above device since sodium system will be provided with cover gas of sufficient positive pressure. Contours of velocity magnitudes and plots of radially averaged axial velocities with and without FDD at the inlet to the annular portion are presented in FIG. 5 and 6 respectively. The significant reduction in flow maldistribution can be clearly seen. The standard deviation (about mean velocity) of radially averaged velocities at annulus inlet reduces significantly from 0.84 without FDD to 0.17 with the device for flow rate of 120 m³/h. Hence, the above concept of FDD is incorporated for all reflux type ALIPs located in auxiliary systems of Indian FBRs.

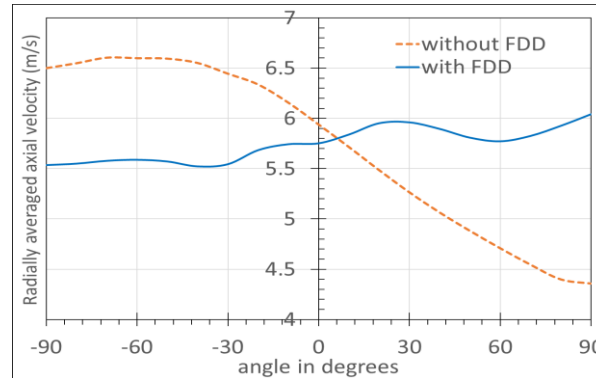


FIG. 6. Circumferential variation of axial velocity at entry to annular portion for 120 m³/h

5. SUMMARY:

Reflux type Annular Linear Induction Pumps are deployed across multiple sodium loops within Indian Fast Breeder Reactors. Drawing from operating experiences, several design improvements are carried out for refining the performance and availability of these ALIPs. The improved design features have undergone testing in both water and sodium loops and found to be effective. These improvements have since been integrated into various sodium loops of FBRs and performing satisfactorily.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] Nashine, B.K., Rao, B.P.C., Design, In-sodium Testing and Performance Evaluation of Annular Linear Induction Pump for a Sodium Cooled Fast Reactor, *Ann. Nuc. Energy* **73** (2014) 527-536, <https://doi.org/10.1016/j.anucene.2014.07.026>
- [2] Sharma, P., Mani, A., Nashine, B.K., Performance Evaluation of a Continuous and a Discontinuous Magnetic Circuit Annular Linear Induction Pump, *Ann. Nuc. Energy* **158** (2021) 108241, <https://doi.org/10.1016/j.anucene.2021.108241>
- [3] Ram Kumar Maity, R. Nandakumar, Juby Abraham, K. Natesan, N. Kasinathan, K. Velusamy, Optimisation of Reflux Head of an Electromagnetic Pump, *Proceedings of the 7th Intl. and 45th National Conference on Fluid Mechanics and Fluid Power*, December 10-12, 2018, IIT Bombay.
- [4] Araseki, H., Kirillov, I.R., Preslitsky, G.V., Ogorodnikov, A.P., Magneto Hydrodynamic Instability in Annular Linear Induction Pump, Part-I. Experiment and Numerical Analysis, *Nuc. Eng. Des.* **227** (2004) 29-50, <https://doi.org/10.1016/j.nucengdes.2003.07.001>.