Testing and Qualification of Trailing Cable system for Prototype Fast Breeder Reactor

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Abstract. Small and large rotatable plugs (SRP & LRP) are provided to facilitate in-vessel handling of core subassemblies using transfer arm. These plugs are rotated during refuelling of the reactor. The control & instrumentation signals and power to various systems / components located on the rotatable plugs are carried by cables and are connected to their respective control panels located outside. Among large number of signals / power supply, some are needed during rotation of the plugs also. Trailing Cable System is conceived and designed to carry power/control cables whose continuity is to be ensured during rotations of SRP & LRP. The design requirement for trailing cable system is to accommodate twist of cables between the stationary roof slab and SRP by 540° while maintaining their continuity, which otherwise is not possible.

The system is designed with a set of posts mounted one each on SRP & LRP and set of overhanging arms through which, cables are routed in a predetermined way. The overhanging arm bring the cables to the centre of SRP / LRP as the case may be and hence avoids pulling and bending of cables, instead results in twisting. The bunch of cables are freely suspended in the form of ‘S’ shape between roof slab centre and SRP centre with a vertical separation of 3 m between clamping points. The free length of cables is designed to accommodate the twist without causing entanglement of cables. Provisions are made to swing the system away for facilitating handling of components over control plug. Interference of trailing cable system with other components, particularly fuel handling machine during plug rotation is taken care during the design.

To carry out functional testing and qualification of the important system, a prototype arrangement between SRP and roofslab was manufactured and erected at full scale Top Shield Layout Model. In line with the approved testing program, the rotatable plugs were rotated by designated angles and twist in cables was critically studied. From the detailed tests, it is observed that the configuration conceived for the supporting structure and the cable routing between SRP and roof slab satisfy the design intent and is capable of maintaining electrical continuity of the cables, meeting functional requirements. Subsequently, the system was qualified through systematic cyclic testing.

Key Words: Fast breeder reactor, rotatable plugs, trailing cables, testing & qualification.

1. Introduction

India is pursuing a well laid out three stage nuclear programme and deployment of fast breeder reactors is envisaged in second stage. In a typical sodium cooled fast breeder reactor like Prototype Fast Breeder Reactor (PFBR), which is in commissioning stage at Kalpakkam, the reactor core is housed inside a reactor vessel called main vessel [1] (Ref. Fig. 1). The heat generated in the core due to fission reaction is removed by the liquid sodium flowing through core and transferred to the water in steam generator through an intermediate sodium circuit. Top shield (or roof deck) forms the top cover for the reactor. It provides biological and thermal shielding in the top axial direction of reactor and provides a leak tight barrier between cover gas and reactor containment building. It consists of a stationary part ‘roof slab’ and rotatable plugs. Two rotatable plugs i.e., small and large rotatable plug (SRP &

LRP) are provided to facilitate in-vessel handling of core subassemblies using transfer arm. These plugs are rotated during refueling of the reactor in shut-down state.

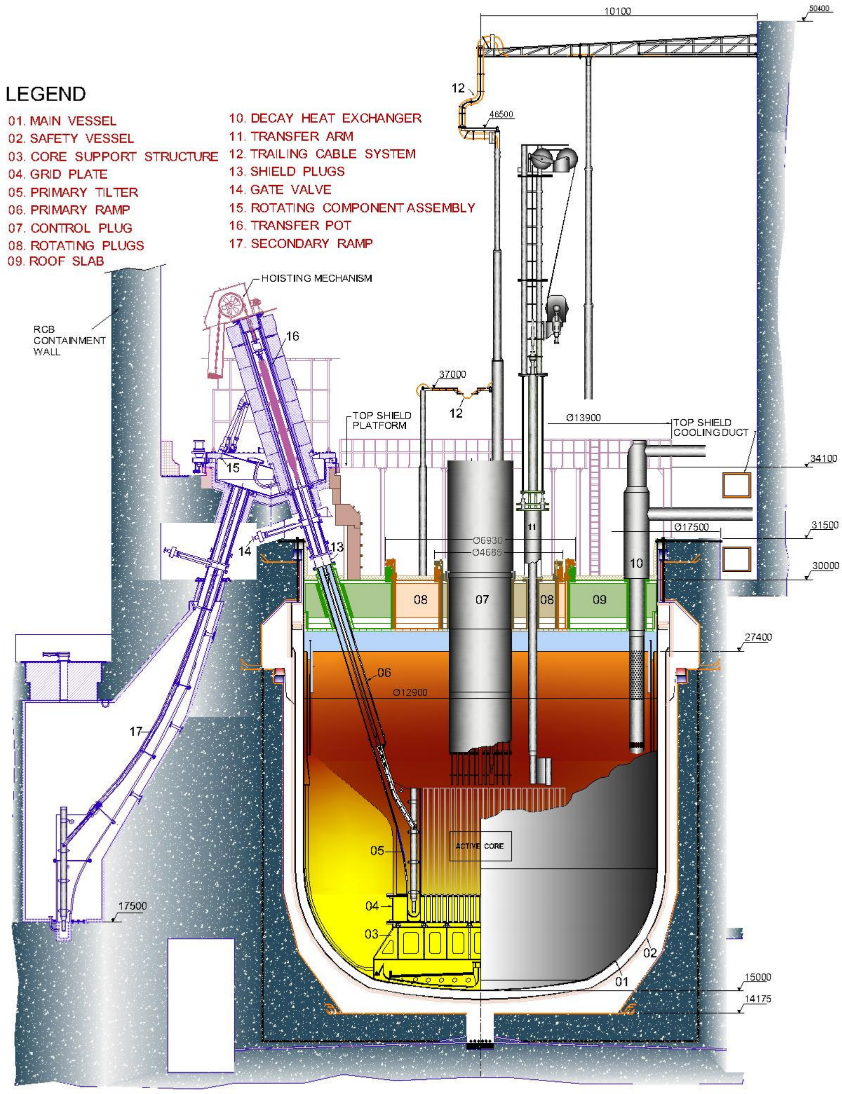

Fig. 1: Schematic of PFBR Reactor Assembly

The cables for the electrical and instrumentation components of individual systems of the reactor are connected to their respective control panel located at field or local control center of respective buildings. The systems/instruments which are outside the periphery of LRP are directly wired to the respective system cabinets/control room using permanent cabling. The systems/instruments which originate from/within the periphery of LRP need to be routed through either disconnectable connector boxes or trailing cable arrangement to enable the rotation of rotatable plugs (SRP/LRP) during fuel handling operation. Signals segregation through disconnectable connector boxes or trailing cable is done based on the requirement during fuel handling operation. To continuously monitor and maintain the safety of the reactor during all the time, important measures like neutron detector signals, CSRDM & DSRDM positions, temperature of few reactor assembly components and top shield argon system signals are also routed through the trailing cable system (TCS). Apart from this the power, control and signal cables of transfer arm and rotatable plugs are also routed through TCS. There are fourteen such trailing cables of diameter varying from 29 to 33 mm.

During the plug rotation, in the course of maintaining continuity, the rotation of the plugs is converted into twist in the cable. TCS consists of several links and joints to carry out this task of converting the rotation into twist in the cables while ensuring no entanglement among cables and also no pulling/pushing loads to the cables. Since, there is no prior experience regarding performance of similar systems, 1:1 scale functional testing of the TCS along with actual size cables was taken-up. Further, since the cables are custom made to the requirements and there are no published information regarding their performance under repeated twisting, qualification testing of the cables used in the trailing cable system formed part of concurrent testing program. The total estimated number of plug rotations in the life time of reactor is 20000. As part of qualification of TCS, a 10% of total life i.e., 2000 cycles was considered for testing. The details of trailing cable system, testing and outcome are brought out in the following sections.

2. Description of Trailing Cable System

The trailing cable system consists of three posts mounted one each on SRP / LRP & roof slab and set of overhanging arms (cantilevers) through which, cables are routed in a predetermined way. The overhanging arms are supported from the posts at a higher elevation in order to avoid interference with transfer arm during rotation of the plugs.

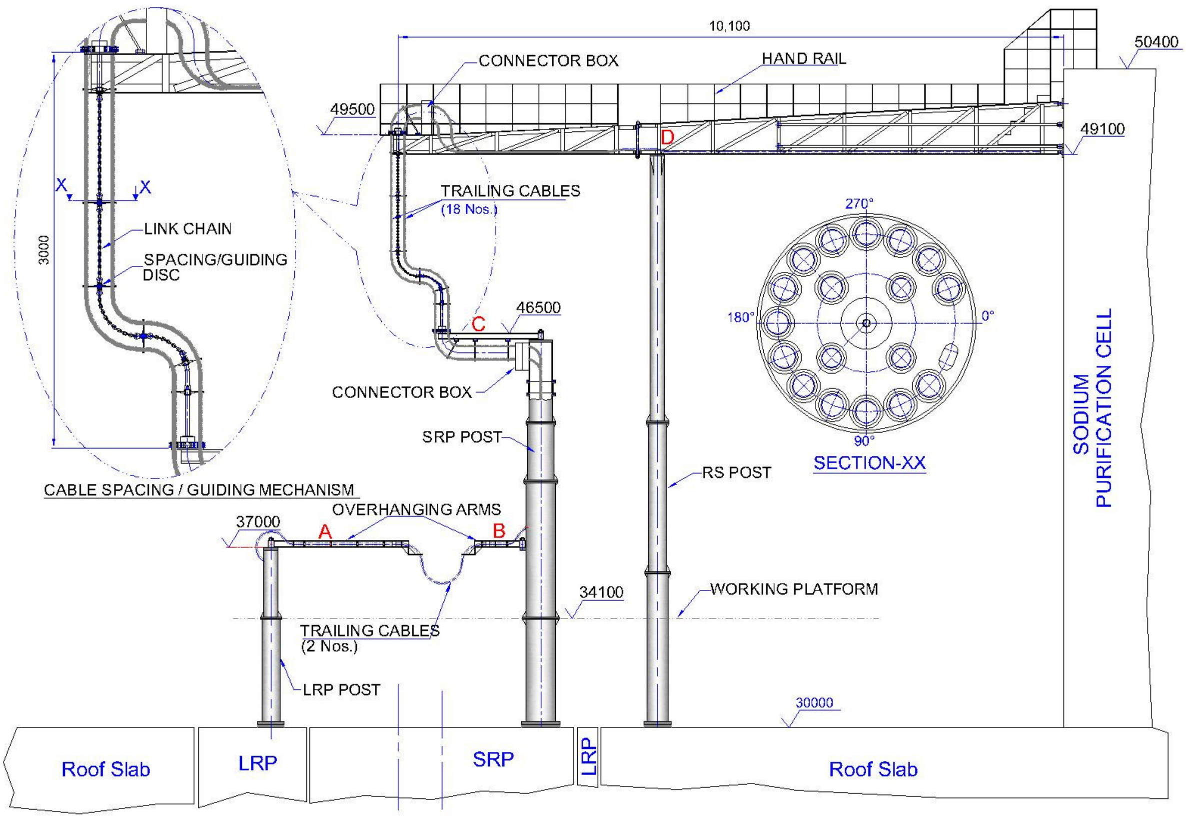

Fig. 2 Schematic of Trailing Cable System

The cables from LRP are first taken up to top of LRP post and routed between LRP - SRP posts through two overhanging arms A & B as shown in Fig.- 2. The loop of cables between the overhanging arms gets twisted whenever SRP is rotated relative to LRP and this span of cable provides the required flexibility during rotation. The maximum rotation of SRP w.r.t. LRP is ½ turns and a free cable length of ~1 m is provided in the loop to accommodate this twist. The overhanging arms are positioned radially towards SRP centre to minimize the extra length of the cables needed during rotation of SRP relative to LRP.

Over SRP, the cables from SRP join those from LRP and are taken up together further along SRP post. The cables are then routed through another set of overhanging arms ‘C’&‘D’ and cable spacing / guiding mechanism to the outside of roof slab. The overhanging arm ‘C’ brings the cables to the centre of SRP where as the overhanging arm ‘D’ which is ~3 m above the arm ‘C’ takes the cables out from the centre of LRP. These two arms are interconnected through the cable spacing / guiding mechanism.

The cable spacing / guiding mechanism consist of clamping discs at the ends and several guiding/spacing discs between them (Fig. 2). The thin circular cable guiding/spacing discs having slots along the periphery for the passage of individual cables, separates and guides the cables when plugs are rotated and thus prevent any entanglement. The discs are supported from the arm ‘D’ through flexible chain links connected at the centre of the discs. Since the maximum angle of rotation of SRP is 180° and that of LRP is 360°, the cables between the two overhanging arms ‘C’ and ‘D’ get twisted to a maximum of 540° (1.5 turns). From the geometrical constraints i.e., location of SRP post and orientation of overhanging frame, the cables will be subjected to a pre-twist of ~60° in reverse direction to that of plug rotation. Hence, the actual twist in the cables will be ~480°. The level difference of 3 m between the two arms ‘C’ and ‘D’ ensures the availability of ~3.2 m of cables to accommodate this twist and this translates to a twist of about 160° per meter length of cable.

3. Objectives of Testing & Qualification

As part of overall functional testing and qualification trials of the trailing cable system as per design intent, following objectives were identified:

- Finalizing assembly / erection methodology.
- Establishing the profile of cables and demonstrating slackness / extra length of the cables provided is sufficient to absorb the total twist of 540° resulting from plug rotations.
- Finalizing the positions of the spacing discs.
- Verifying the smooth sliding of the cables through the discs and bringing out the required measures to ensure the same.
- Demonstrating smooth twisting & untwisting of the cables.
- Demonstrating overall functionality of the mechanism.
- Demonstrating satisfactory performance of cables over 2000 cycles of plug rotations as part of qualification.

4. Experimental Set-Up & Installation of Trailing Cable Mechanism

The trailing cable system has been erected over Top Shield Layout Model (TSLM), a facility built to verify the layout of equipment over top shield (Fig. 3). The facility is provided with rotatable plug models as in reactor. To facilitate their rotation, these plugs are mounted over large diameter bearings. The rotatable plug models in experimental set-up are bottom supported, over the bearings (Fig. 4). The LRP & SRP drive motors are controlled using VFD. To sense the end limits and to prevent over travel, limit switches are provided. The limit switches are wired to the control circuit of the VFD panel. All the tests were conducted in the ambient temperature.

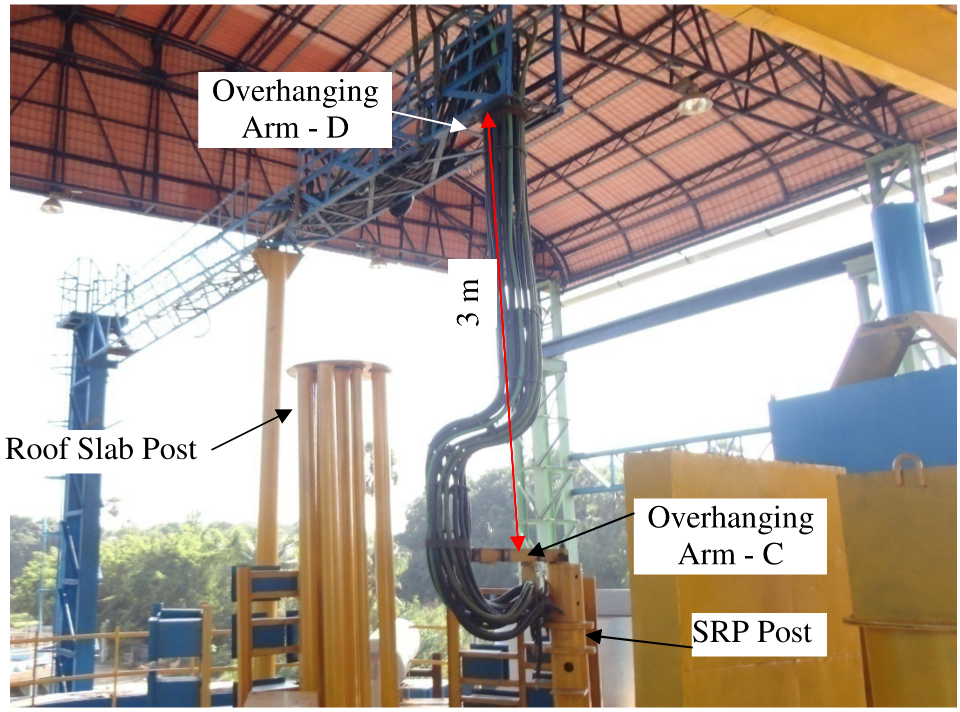

Fig. 3: Top View of the Model

Fig. 4: Drive Arrangement for Plugs in TSLM

For functional testing & qualification purpose, the cable arrangement from roof slab to SRP is only considered as the number of cables to be routed between them is very large i.e., 18 Nos. and also, the total twist to be absorbed is 540° whereas, since only two cables are routed between SRP and LRP with the relative rotation limited to 180°, the same is not accounted. The mechanical parts of TCS were fabricated in carbon steel material. The mechanical system as well as cables were intergated over TSLM, sequentially for the purpose of testing. Following step by step procedure was adopted:

i. Fixing of top clamping disc and its base plate in position at the indicated positions in overhanging frame (Arm 'D' in Fig. 2).

ii. Introducing the required length of cables through top clamping disc, with free length of cables hanging down and clamping the cables to the top disc.

iii. Fixing of top cable guiding arrangement.

iv. Insertion of guiding and spacing discs (3 Nos. each) through the cables.

v. Positioning of top guiding disc within the top cable guiding arrangement.

vi. Fixing of bottom clamping disc along with its base plate at the indicated location in over-hanging beam (Part 'C' in Fig. 2).

vii. Fixing the bottom cable guiding arrangement over bottom clamping disc.

viii. Inserting the cables one by one through the bottom guiding and clamping discs.

ix. Positioning the guiding discs over the bottom cable guiding arrangement.

x. Before clamping the cables with the bottom clamping disc, the required length of cables within the cable spacing/guiding mechanism needs to be adjusted so as to provide the additional length of cables needed during the twisting of bunch of cables through 540° wherein cables are located over a PCD of 270 mm. This additional length, which ensures that cables are neither pulled nor pushed when plugs are rotated is estimated to be 300 mm, with a margin of 50 mm (ref. Fig. 5).

xi. The cables are clamped with the bottom clamping disc after ensuring 300 mm extra length of cables are provided within the cable spacing/guiding mechanism. The bunch of cables were given a 'S' shape so that the extra length of cables could be accomodated within the top & bottom clamping discs without any sagging or distorted shape.

xii. Positioing one number of spacer disc (Spacer Disc - 3) at the centre of horizontal leg of cable and two more spacer discs (Spacer Discs 1 & 2) in the vertical drop of cable from top with a spacing of 900 mm as indicated in Fig. 6.

xiii. Interconnecting the discs with chain to ensure retainment of their position.

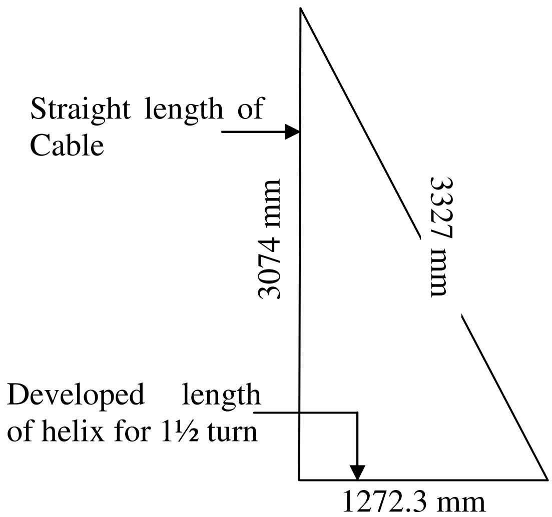

Fig. 5: Additional Length of Cables required to Accommodate Twist

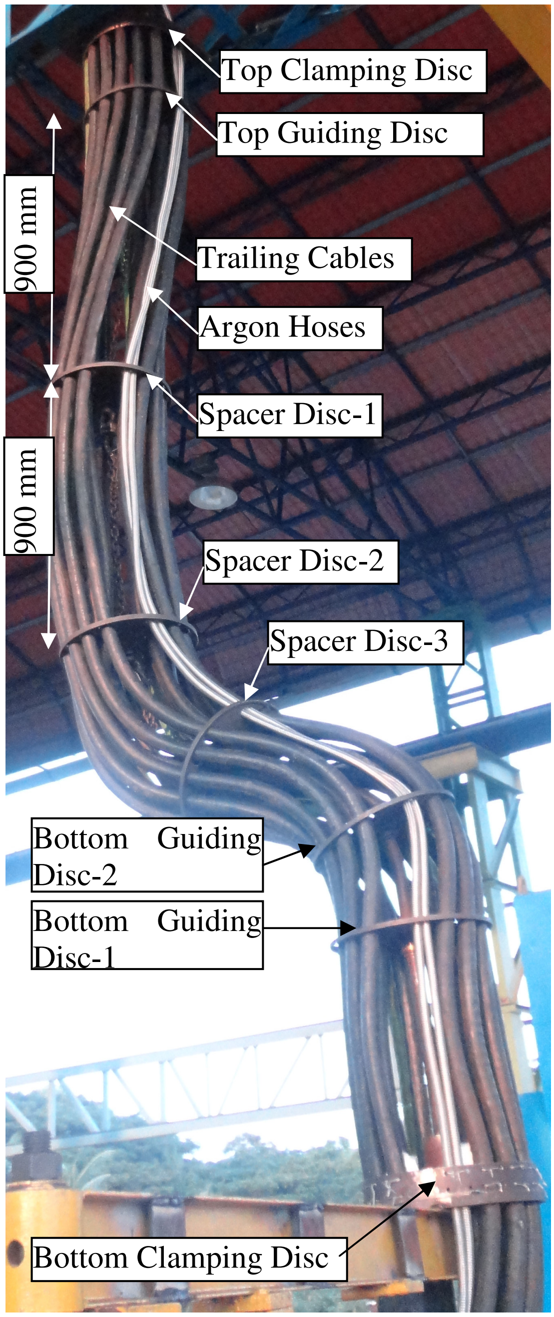

Fig. 6: Positioning of Guiding and Spacer Discs in Trailing Cable System

The shape of bunch of cables between the top and bottom clamping discs after their fixing is shown in the Figure 6.

5. Qualification Criteria

In line with the qualification requirements for cables, following tests were identified :

Before starting of the test and after completing 2000 cycles:

i. Physical verification on cable outer sheath: There shall not be any twisting or damage on the outer sheath.

ii. Testing of insulation resistance on all the cables as per IS 10810 Part 43

iii. Testing of conductor resistance of all the wires on the cables as per IS 10810 Part 5

After every 500 cycles:

i. Testing of conductor resistance of all the wires on the cables as per IS 10810 Part 5

6. Testing and Observations

Subsequent to erection of system over TSLM, the plugs were rotated in to & pro motion to observe and verify the functionality of trailing cable mechanism. The movement of various links was observed and behaviour of cables bunch is studied as the plugs are rotated. The shape of the bunch of cables at different stages, viz., home position, after rotation of LRP by 360° and after additional rotation of SRP by 180° are shown in Figure 7 (a)-(c).

a. SRP - 0° & LRP - 0° b. SRP - 0° & LRP - 360° c. SRP - 180° & LRP - 360°

Fig. 7: Profile of Trailing Cables under Different Plug Positions

Following are the observations from the functional testing:

- The mechanism conceived is capable of accommodating the twisting of the cables during rotation of the plugs.
- The winding and unwinding of cables and its shape was repeated, each cycle.
- An additional cable length of 300 mm is sufficient between the two clamping discs to have uniform twisting of the cables without entanglement.
- Teflon bushes at the interface of the cables and the passage holes in the discs will help in smooth sliding.
- The location of spacing discs obtained based on the observations during testing to be implemented in reactor.

Subsequent to functional testing and with the finalized location of various discs, cyclic testing of TCS was undertaken as part of qualification. Towards this, the plugs were rotated for 2000 cycles, each cycle consisting of one forward and reverse rotation of SRP & LRP. The insulation and conductor resistances were measured as per the qualification criteria indicated in Section 5. After 2000 cycles of testing, following are the observations:

- There were no difference between the values measured viz., insulation resistance and conductor resistance of all the cables before and after testing.
- There were no physical damages and twisting found in the cable after the cycle tests.

7. Conclusions

In PFBR, two Nos. of rotatable plugs are provided to facilitate handling of fuel subassemblies for re-fuelling through in-vessel transfer machine. Since, these plugs are rotated for positioning the handling over required fuel assembly to be handled, maintaining continuity of cables transmitting electrical, control & instrumentation signals from/to rotatable plugs is a challenging task. The trailing cable system arrangement ensures continuity of these cables, even under plug rotation during reactor shutdown state, between equipment located within rotatable plugs and their corresponding control panels located outside the plugs. The system consist of tall posts, which are mounted over rotatable plugs and interconnected through set of overhanging arms and cable spacing/guiding arrangement. The arrangement through which the cables are routed ensures that during the plug rotations, the rotation motion is converted into twisting of cables. Required amount of free length of cables is provided within the cable spacing/guiding arrangement to absorb this twist. The 1:1 scale functional testing of trailing cable system has demonstrated the functionality of the system in meeting the design intent. Subsequent cyclic testing for 2,000 cycles has demonstrated the resilience of the system for the intended application.

8. References

[1] Chetal, S. C., et al., The design of the Prototype Fast Breeder Reactor, Nuclear Engineering and Design, 236 (2006), pp 852-860.