Design and Development of Stroke Limiting Device for Control & Safety Rod Drive Mechanisms (CSRDMs) of future FBRs

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Abstract. For Anticipated Transients Without Scram (ATWS), the time margin leading to core damage is relatively small in comparison with Loss of Heat Removal System (LOHRS). Significant mechanical energy release, derived from prompt criticality in a core disruptive accident, has to be practically eliminated, as it has the potential to breach the reactor vessel and to significantly affect the integrity of the containment. Thus, means for passive or inherent reactor shutdown are necessary for core damage prevention. In this context the following are the important decisions related to shutdown systems for next generation SFRs to facilitate practical elimination significant mechanical energy release due to Anticipated Transients Without Scram. i) Strengthen the first two shutdown systems by addition of passive/active features. ii) Introduce an ultimate shutdown system, which is completely diverse, independent, passive & confined within core sub-assembly. This shall come into action on failure of first two systems. In this paper, design augmentation of first shutdown system by addition of an active safety device is discussed. The first shutdown mechanism of future FBR is Control and Safety Rod Drive Mechanism (CSRDM). A Stroke Limiting Device (SLD) is provided in CSRDM to prevent inadvertent withdrawal of Control & Safety Rods beyond a pre-set level and thereby limit the consequences of inadvertent control rod withdrawal event well within limits even with the failure of other safety actions. SLD limits the consequences of inadvertent withdrawal of CSR by physically limiting the withdrawal stroke length of CSR to 20 mm.

Two different concepts of SLD have been conceived, manufactured and standalone endurance tested. One of them has also been integrated with CSRDM and tested. Based on the above, Mark-II design of SLD with some additional design improvements is being developed. The final design of SLD (Mark - II) will be adopted in CSRDM for future Fast Breeder Reactors. The details of two concepts developed, testing carried out as part of design validation and design improvements being incorporated in Mark-II design are presented in this paper.

Key Words: Stroke Limiting Device, Control and Safety Rod Drive Mechanism, Fast Breeder Reactor, Transient Over power Event

1. Introduction

The Generation IV nuclear reactor safety guide lines states that the radiation exposure to the public should be made a practically eliminated event and the design of the reactor system shall encompass some postulated severe accidents as Design Extension Conditions (DEC), which were not addressed in earlier designs and were considered as a Beyond Design Basis Event (BDBE). Core disruptive accident (CDA) in fast reactor is a severe accident influencing primarily the design of the containment and subsequent controlled release of radioactivity to the public. Efforts are being made in recent times to reduce the potential of energetic CDA by reducing the sodium void coefficient of reactivity and by improving the shutdown system and decay heat removal system capabilities with additional active and passive features. Unprotected loss of flow (ULOF) and Unprotected transient over power (UTOP) are two scenarios which influence design of shutdown systems and which can lead to

CDA. UTOP and ULOF are together classified as Anticipated Transients Without Scram (ATWS).

For Anticipated Transients Without Scram (ATWS), the time margin leading to core damage is relatively small in comparison with Loss of Heat Removal System (LOHRS). significant mechanical energy release, derived from prompt criticality in a core disruptive accident, has to be practically eliminated, as it has the potential to breach the reactor vessel and to significantly affect the integrity of the containment. Thus, means for passive or inherent reactor shutdown are necessary for core damage prevention [1]. In this context the following are the important decisions related to shutdown systems for next generation SFRs to facilitate practical elimination significant mechanical energy release due to anticipated Transients Without Scram. i) Strengthen the first two shutdown systems by addition of passive/active features. ii) Introduce an ultimate shutdown system which is completely diverse, independent, passive & confined within core sub-assembly. This shall come into action on failure of first two systems. Design augmentation of first active shutdown system by addition of an active safety device (Stroke Limiting Device) is discussed in this paper.

These improvements in the FBR shutdown system will enhance the safety and reliability. This in turn will increase the public confidence on the FBR and Nuclear power program on the whole.

2. Stroke limiting device

A Stroke Limiting Device is proposed in CSRDM of future FBR to prevent inadvertent withdrawal of Control & Safety Rods beyond a pre-set level and thereby limit the consequences of inadvertent control rod withdrawal event well within category II design Safety Limits. SLD limits the consequences of inadvertent withdrawal of CSR by physically limiting the withdrawal stroke length of CSR to 20 mm.

In the design of stroke limiting device, uncontrolled withdrawal of only one control and safety rod is considered. This is due to the fact that banking of control and safety rod is not there in the operating philosophy. At any given time, only one rod can be selected for raising operation. The withdrawal limit allowed by stroke limiting device will limit the reactor power to 103 % of nominal power for a 500 MWe oxide fuelled reactor similar to PFBR. This corresponds to 25 mm withdrawal and with some margin on uncertainties, the stroke limit is fixed at 20 mm. The power escalation due to control and safety rod withdrawal of 27.5 mm (PL check, fig shows 27.5 mm)is shown in Figure 1. The schematic of Stroke Limiting

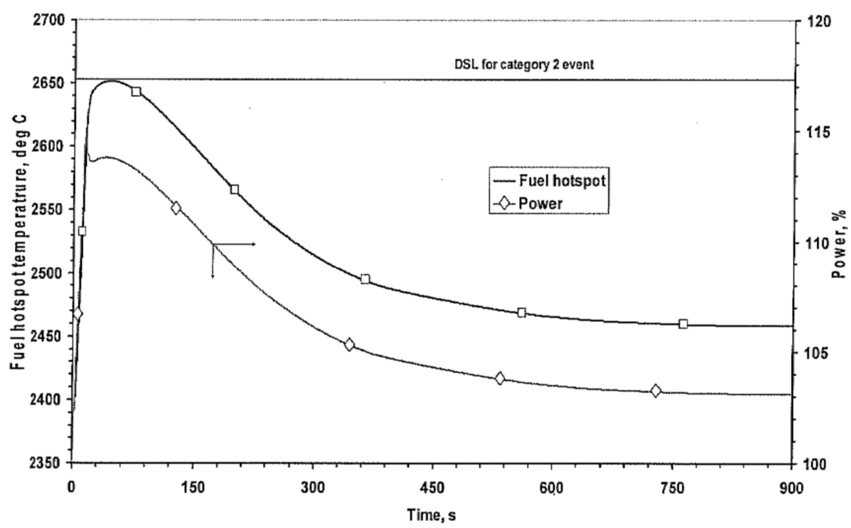

Figure 1: Power and temperature evolution following a control rod withdrawal of 27.5 mm

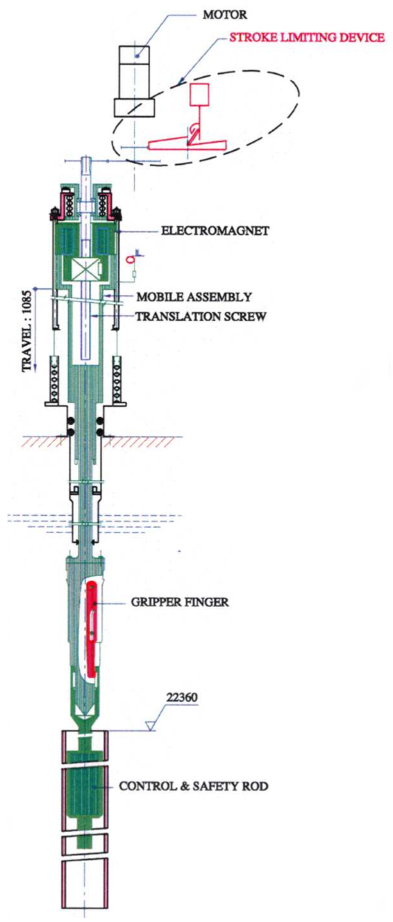

Figure 2: Schematic of CSRDM integrated with SLD

Device with CSRDM is shown in the Figure 2.

The SLD is coupled to the drive line of the CSRDM, which drives the screw nut assembly. The Screw nut assembly translates the mobile assembly of CSRDM along with control and safety rod when gripped by CSRDM. The screw nut assembly holds the mobile assembly with the help of an electromagnet. The electromagnet upon scram signal gets de-energised and drops the mobile assembly along with control and safety rod under gravity to shutdown the reactor. The SLD is placed in the drive line hence addition of the same will not affect the scram function. During scram, the translating mobile part is detached from the electromagnet and falls under the influence of gravity.

3. Design and development of SLD

The following basic design criteria have been laid out for the conceptual design of SLD.

- The design of the SLD shall be made such that it can be assembled with the CSRDM without much change in configuration. It is preferable to introduce it in the upper part of CSRDM as upper part is in benign environment compared to lower part.
- It shall be modular in design, to facilitate its independent testing and final retrofitting in prototype mechanism.
- The SLD shall become operational just before CSR reaches the critical level (i.e., ~ 320 mm for a 500 MWe core configuration)from the bottom most position of CSR. The reactor will still be sub critical by more than 1% on reactivity (K_{eff}<0.99) if continuous withdrawal of one control rod below this critical level takes place.
- The SLD shall allow only a travel of 20 mm (known as allowable stroke) at a stretch for

the upward movement of mobile assembly. Provision to reset the SLD shall be made to facilitate further upward travel on demand.

- Continuous lowering of mobile assembly should be possible at any time and under any condition.
- The SLD shall be fail safe i.e., the failure of SLD shall not impair the downward movement of mobile assembly.
- The applicable classification/categorization for SLD is as given below. This is same as that specified for CSRDM.

Safety class	:	Class 1
Design Class	:	Class 1
Manufacturing class	:	Class 1
Seismic category	:	Category 1

- The system shall have appropriate instrumentation to sense the end of stroke and control logic to stop the motor so that upward movement of the mobile assembly is terminated.
- SLD shall not hinder the manual operations on CSRDM & shall not call for dismantling to do any manual operation.

3.1 Conceptual design

Based on the design requirements stated above, different concepts of SLD were studied and two concepts of SLD were finalised for detailing and development. The details of the two designs are discussed in the following paragraphs.

3.1.1 Description and operation of Type 1 SLD

Figure 3. Shows the schematic of various components of the SLD Type 1. The power from the main drive shaft is fed to driving pinion. The driving pinion is coupled to the gear of SLD. The SLD gear top surface is profiled with a ramp. The start/end of ramp has a vertical face which is known as stopper. A teflon roller fixed on a swing arm slides over the ramp on the gear. The swing arm is fixed on the plunger with pin joint. The inclined position of the plunger is maintained by a helical coil spring. When the SLD gear rotates, the ramp on the gear raise/lower the plunger based on the direction of rotation. The plunger is housed inside a guide way. A Solenoid connected to the plunger facilitates resetting operation by pulling the plunger up. The plunger is always pushed downwards by gravity and a compression spring. Micro-switches are fixed on micro-switch support which in turn is fixed on plunger. The micro-switch is actuated by cam fixed on swing arm. The position of the swing arm is sensed by the micro-switch and signals the control system to either switch of the drive motor (by first micro-switch) or scram (second micro-switch) the reactor.

a. Raising operation

During raising operation, main drive motor drives the pinion in counter clock wise direction. The pinion drives the SLD gear. The plunger assembly slides on the top of the SLD gear ramp in raising direction. When the SLD gear completes one rotation, the stopper in the gear will push against the swing arm. The swing arm which is normally in inclined condition is rotated to vertical position by the stopper. This movement in the swing arm is sensed by the micro-switch 1 and signals the reach of allowable stroke and stops the main drive motor, authorises the operator to reset the SLD for further raising.

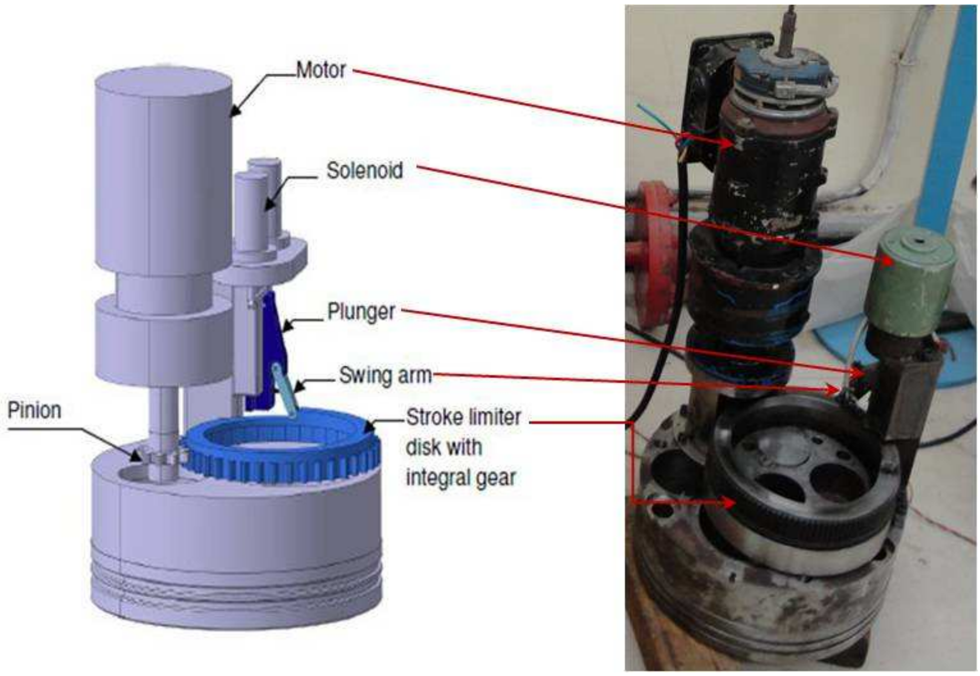

Figure 3: Schematic and photograph of SLD Type-1

b. Resetting operation

When the main drive motor is stopped by SLD after reaching allowable limit, resetting of SLD by operator is required for further rising of CSR. In this condition, the swing arm is in vertical condition and the micro switch -1 is de-actuated. Resetting is done with the help of DC pull type solenoid. On pressing the resetting switch in the control panel the solenoid pulls up the plunger assembly. When the solenoid fully withdraws the plunger assembly, the swing arm is raised above the stopper. Now the swing arm is free to open to its normal inclined position. The swing arm comes to its inclined home position with the help of a coil spring attached to it. On reaching the inclined position, the swing arm actuates the micro switch 1. The actuated micro switch cuts power supply to the solenoid. The plunger assembly falls down under the action of gravity assisted by compression spring. The swing arm now rests above the stopper face of the SLD gear and thus further rising of CSR is facilitated.

c. Lowering operation

During lowering operation, motor drives pinion in clock wise direction. The swing arm slides upward on SLD gear ramp & slips over the stopper in the lowering direction.

3.1.2 Description and operation of Type 2 SLD

Figure 4. shows the schematic of various components of the SLD. The power from the main drive shaft is fed to driving gear. The driving gear is coupled to the pinion of SLD, which drives the ball screw shaft through free wheel clutch and electromagnetic clutch. The nut in the ball screw translates up and down which is analogous to the CSR translation movement. The stopper in the top and bottom is provided with top and bottom limit switches respectively. The switches are used for the control logic of the SLD and to give the status of SLD. A helical coil spring is provided on top of ball screw nut to assist the downward movement of the nut during resetting operation. The electromagnetic clutch is normally engaged type(by springs provided inside the clutch).

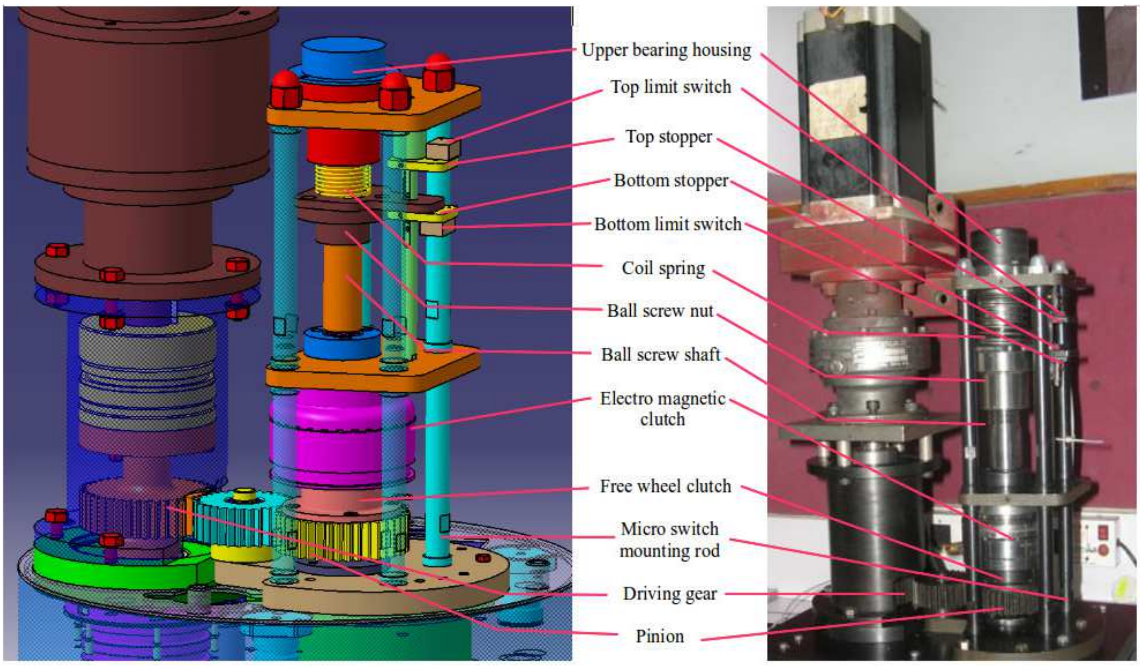

Figure 4: Schematic and photograph of SLD Type-2

a. Raising operation

When main drive motor is driven in raising direction, gears, free wheel clutch and electromagnetic clutch drive the ball screw, the ball screw traverses the nut from bottom to top position. On reaching the top position, motor is stopped by the signal from top limit switch. The limit switches are placed such that they are actuated ahead of physical contact of the nut with respective stopper.

b. Resetting operation

After reaching the top limit, ball screw nut in top position should be brought to bottom position for further raising operation. When electromagnetic clutch is energised, main drive line is separated from the SLD unit. During this disengagement, ball screw nut falls down under gravity which is triggered and assisted by the coil spring. After reaching bottom limit, bottom limit switch is activated and this switches off the power supply to the electromagnetic clutch and the drive line is again re-engaged. After this, further rising of CSR by 20 mm is facilitated.

c. Lowering operation

During lowering operation, motor drives the main drive shaft and the drive gear in clock wise direction. The free wheel clutch slips in lowering direction and transmits no motion to the SLD unit and hence there is no restriction for lowering operation.

4. Qualification of SLD Type 1 and Type 2

Prototype SLD Type-1 and Type-2 were manufactured and functional test for few cycles were done. The stand alone endurance testing of SLD was performed with PLC based control panel. The control panel was equipped with three phase contactor for driving the main drive motor, relays for motor and electromagnetic clutch/solenoid, terminals for micro switches and a power supply unit. On the panel, control buttons were provided for various operations in SLD along with light indicators for indicating status of SLD operation. After few initial trials the testing was automated. Periodic monitoring was done to ensure the proper functioning of the system.

The SLD Type -1 operated continuously without any interruption for about 49003 cycles in raising direction and 258 hours in lowering direction. The SLD Type-1 is qualified for 14 years of reactor operation by this stand-alone testing.

The SLD Type -2 operated continuously without any interruption for about 34523 cycles. This amounts to ~ 10 years of reactor operation. However during initial and towards end of testing, the SLD performed inconsistently. Design modifications were required to make this design more rugged. Because of the use of carbon bush contactor in EM clutch, it gave sparks during operation hence the use of EM clutch was not preferred. In this context it was decided to stop further development of type-2 SLD. Based on good performance, the type-1 design was selected for integration with CSRDM

A new PLC based control panel was made for testing the integrated functioning of CSRDM with SLD. The SLD was assembled with CSRDM and all I & C connections were made to the control panel. Figure 5 Shows the SLD integrated with CSRDM. Totally, thirty translation cycles were carried out. Performance of the mechanism was smooth during testing, demonstrating the integrated performance of CSRDM with SLD.

Few minor observations made during the integrated testing were taken up and improved design of SLD named mark –II has been made. The SLD mark –II design is in its advanced stage. The Mark –II design will be developed and integrated testing along with CSRDM for life of 40 years will be done. The SLD Mark-II design is shown in Figure. 6.

Figure 5: Photograph of Stroke limiting device integrated with CSRDM left & SLD unit- right

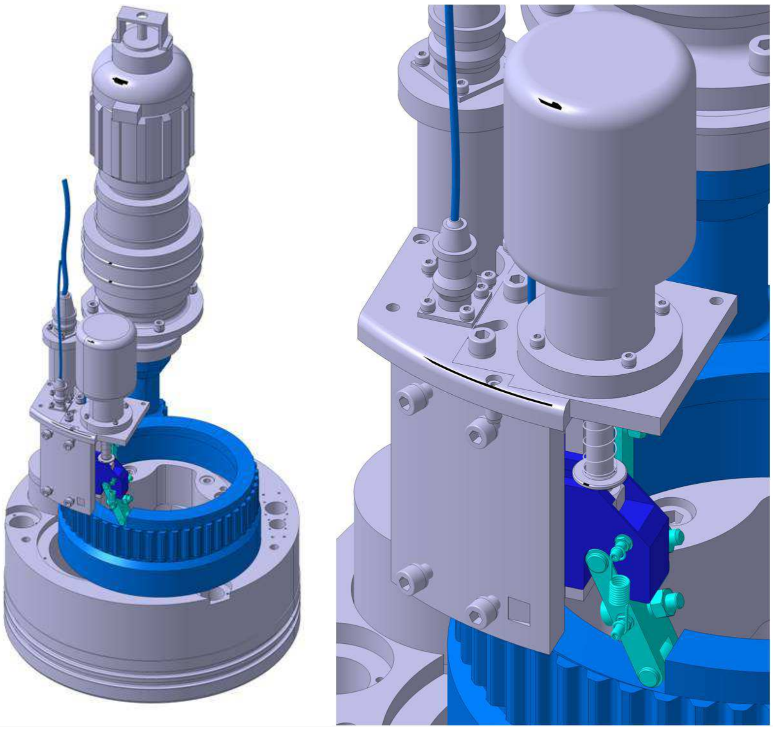

Figure 6: 3D model of SLD mark-II design

Design improvements for SLD Mark-II design are listed as follows.

- Micro-switches were repositioned from moving components to stationary components for rugged performance.
- Design is modified to facilitate all manual operation on CSRDM without dismantling
- Cabling scheme has been improved and Cover for SLD provided.

5. Summary

The design and development of SLD to address the transient overpower event in FBR has been elaborated in this paper. The requirements, conceptual design and qualification of SLD have been briefed. The mark –II design of SLD after qualification for life will be part of CSRDM of all future INDIAN FBRs. With the addition of SLD to the shutdown mechanism the potential cause of the transient over power event is addressed. This also pushes the Unprotected Transient Over Power event which is presently a Beyond Design Basis Event (BDBE) to Design Extension Condition(DEC).

Appendix 1: References:

[1] The Safety Design Criteria Task Force Of the Generation IV International Forum , "Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System" SDC report SDC-TF/2013/01 May 1, 2013 pq 90.