Introduction

BARC and NPCIL have entered into MoU for design and development of drive mechanisms for adjuster rods, control rods and shut-off rods of Tarapur Atomic Power Projects (TAPP) - 3 & 4.

Under the MoU, Division of Remote Handling & Robotics (DRHR), BARC, shall carry out the design and development of prototype drive mechanisms and issue detailed drawings and specifications to NPCIL so as to meet the TAPP-3&4 project schedule requirements. The BARC drawings and specifications shall be directly used by NPCIL for production of drive mechanisms for TAPP - 3 & 4.

DRHR, BARC, has designed cable winch drive mechanisms for adjuster rods, control rods and shut-off rods of TAPP - 3 & 4 incorporating a number of advanced features. These mechanisms are significantly different from the mechanisms used in Dhruva, Kamini and 220 MWe PHWRs. The prototype drive mechanisms are being tested on full scale test station at BARC for design validation. The tender drawings (total 240 nos.) and specifications for production of drive mechanisms have been issued to NPCIL. Under the MoU , NPCIL shall maintain the authenticity of drive mechanism drawings made by BARC. The clearance for production shall be given on completion of testing of prototype mechanisms at BARC.

Functional Requirements

The drive mechanisms are designed to meet the following functional requirements:

- Raising, lowering & holding of rods
- Position indication & limit position indication
- Scram characteristics
- Size constraints
- Environmental conditions
- Remote engagement/ disengagement
- Limited reactivity addition capability
- Fail-safe, non-reverse scram characteristics
- Service life requirements
- Trips, alarms & indications to check safe operation & healthiness
- Reliable, non-dependent on external power source for safety action
- Minimum periodic maintenance

Basic Design Specifications: The basic design specifications for the drive mechanisms are as follows:


**Shut-off Rod/ Control Rod Drive Mechanism:**
During normal reactor operation, shut-off rods/control rods are held through electromagnetic clutches for fail-safe operation. On de-energisation of clutches, the rods fall freely under gravity. The drive mechanisms for shut-off rods and control rods are identical. The shut-off rod element contains an orifice at its top end which comes into action at 80% downward travel of the rod and limits its free fall speed. The control rod element contains an orifice at its bottom end to limit its free fall speed. The hydraulic dashpot is designed to gradually reduce the speed of shut-off rod/control rod during 90% to 100% downward travel.

**Adjuster Rod Drive Mechanism:** The adjuster rod drive mechanism is designed for raising and lowering of adjuster rods at controlled speeds and does not contain electromagnetic clutch or hydraulic dashpot.

<table>
<thead>
<tr>
<th><strong>Property</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shut-off rods</td>
<td>28</td>
</tr>
<tr>
<td>Number of control rods</td>
<td>4</td>
</tr>
<tr>
<td>Number of adjuster rods</td>
<td>17</td>
</tr>
<tr>
<td>Reactivity worth of shut-off rods</td>
<td>72 mk</td>
</tr>
<tr>
<td>Total travel of shut-off rod / control rod</td>
<td>6600 mm</td>
</tr>
<tr>
<td>Weight of shut-off rod / control rod</td>
<td>50 kg</td>
</tr>
<tr>
<td>Time to raise shut-off rod / control rod (at max speed)</td>
<td>150 ± 10 s</td>
</tr>
<tr>
<td>Total length of shut-off rod / control rod</td>
<td>5500 mm</td>
</tr>
<tr>
<td>Reactivity addition rate during withdrawal of rods</td>
<td>≤ 0.33 mk/s</td>
</tr>
<tr>
<td>Max linear speed during withdrawal of shut-off rod / control rod</td>
<td>56.5 mm/s</td>
</tr>
<tr>
<td>Drop time for 5940 mm (90% travel) of shut-off rod, excluding signal processing and actuation delay</td>
<td>1.8 ± 0.1s</td>
</tr>
<tr>
<td>Speed variation of adjuster rods / control rods</td>
<td>15 kg</td>
</tr>
<tr>
<td>Weight of adjuster rod</td>
<td>70 ± 10 sec</td>
</tr>
<tr>
<td>Time to raise adjuster rod at max speed</td>
<td>4 sec approx.</td>
</tr>
<tr>
<td>Drop time for 5940 mm (90% travel) of control rod</td>
<td>Anywhere upto 100% drop</td>
</tr>
<tr>
<td>Partial drop distance for stepback function of control rod</td>
<td>65°C</td>
</tr>
<tr>
<td>Max ambient temperature for mechanisms</td>
<td>65°C</td>
</tr>
<tr>
<td>Max radiation field for mechanisms</td>
<td>10 R/hr</td>
</tr>
<tr>
<td>Applicable code</td>
<td>ASME Boiler and Pressure Section III, NB and for OBE &amp; SSE</td>
</tr>
</tbody>
</table>
**Sub-assemblies:**

1. Motor sub-assembly
2. Worm gear sub-assembly
3. Electromagnetic clutch sub-assembly
4. Reduction Unit-I sub-assembly
5. Mechanism housing sub-assembly
6. Sheave shaft sub-assembly
7. Potentiometer sub-assembly
8. Reduction unit-II sub-assembly
9. Hydraulic dashpot sub-assembly
10. Limit switch sub-assembly
11. Reed switch sub-assembly

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1. Motor sub-assembly
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5. Mechanism housing sub-assembly
6. Sheave shaft sub-assembly
7. Reed switch sub-assembly
**Salient Design Features:** The salient design features of drive mechanisms are as follows:

- 28 shut-off rods constitute the Primary Shutdown System. 4 control rods and 17 adjuster rods constitute Reactor Regulation System. The unavailability of the Primary Shutdown System shall not exceed $10^{-3}$ year/year.
- Heavy water moderator is used for cooling of shut-off rods, control rods and adjuster rods. A perforated guide tube surrounds each shut-off rod, control rod and adjuster rod. The guide tubes for shut-off rods and control rods are identical.
- The drive mechanism is flange mounted on top of guide tube extension and it forms part of pressure boundary for heavy water moderator system.
- The drive motors in the drive mechanisms operate on 3 phase 220V, 50 Hz. The drive motors for control rods and adjuster rods are designed for variable speed (10% to 100%).
- Simplified absorber element design to facilitate easy inspection and replacement of wire rope used for attaching the absorber element to the drive mechanism.
- The electromagnetic clutch operates on 90V dc. Clutch design and torque capacity are suitable to permit partial release of shut-off rod from parking position for checking healthiness of drive mechanisms. Clutch design and torque capacity are also suitable to permit re-arresting control rod after release for reactor stepback function.
- 90% free fall of shut-off rod/control rod (without dashpot) for highest reliability and consistent performance. Maximum free fall speed of shut-off rod element is limited through the use of an orifice at its top end (orifice is effective during 80% to 90% downward travel of shut-off rod). Maximum free fall speed of control rod element is limited through the use of an orifice at its bottom end.
- Hydraulic dashpot incorporates an oil window connected to low pressure side. Above the oil level, the window has adequate space for expansion of oil at high ambient temperature.
- The conventional single vane replaced by double vane to balance forces on dashpot shaft.
arising from high oil pressure during damping action.

- A screw for controlling oil bypass from high pressure side to low pressure side for adjusting damping characteristics of dashpot.
- Modular design of drive mechanism layout to permit in-situ maintenance/replacement for individual sub-assemblies, e.g. motor and worm gear, clutch, dashpot, switchgear, potentiometer, etc without opening moderator pressure boundary.
- Better lubrication for gears, bearings, pick-up rings and spiral springs for long wear life.
- Rope sheave in place of rope-drum to eliminate chances of wire rope coming off the drum groove.
- Provision of single turn triplicate potentiometer on dashpot shaft to monitor retrieval of spiral spring while the rod is being raised. Raising of the rod will get inhibited incase of unsatisfactory retrieval of dashpot shaft. Rationality checks on potentiometer signal shall be done to detect potentiometer failure.
- Provision of multiturn dual potentiometer to monitor continuous position of rods. Rationality checks on potentiometer signals shall be done to detect potentiometer failure.
- Provision of rugged triplicated switchgear unit to monitor shut-off rod drop time for 90% fall.
- Gear reduction trains for potentiometer and limit switches are eliminated.
- Provision of one set of triplicated reed switches (directly actuated) to indicate shut-off rod fully out position for motor cut-off. Second set of reed switches shall be wired to the safety channels of protective system.

Design Testing of Prototype Units

- Effect of initial accelerating spring on rod drop dynamics
- Optimisation of orifice in shut-off rod element for rod drop dynamics
- Optimisation of orifice in control rod element for rod drop dynamics and clutch resetting
- Effect of hole in guide tube stopper plate on rod drop dynamic
- Effect of perforations in the guide tube on rod drop dynamics
- Effect of water level variation in calandria on rod drop dynamics
- Optimisation of partial release characteristics of shut-off rod for on-line testing
- Effect of moderator cross flow on rod drop dynamics
- Effect of dashpot by-pass screw adjustments on rod drop dynamics

Qualification of Special Hardware Items on Test Rigs

- Simulated testing and qualification of dynamic shaft seals used in sheave chamber and dashpot for 50,000 cycles.
- Simulated testing and qualification of spiral spring, rotary switchgear and potentiometers for $10^4$ cycles.
- Simulated testing and qualification of reed switch unit for $10^6$ cycles.
- Qualification of drive motor and electromagnetic clutch.
- Qualification of wire rope & its crimped terminals.
MECHANICAL SHAFT SEALS FOR SHEAVE SHAFT

ATM. FLUID : AIR
ATM. PRESSURE : 1.44 kg/cm² (g)
ATM. TEMPERATURE : 65° C

FLUID TO BE SEALED : OIL
FLUID PRESSURE : 14 kg/cm² (g)
FLUID TEMPERATURE : 65° C

MECHANICAL SHAFT SEALS FOR HYDRAULIC DASHPOT

<table>
<thead>
<tr>
<th>S.No</th>
<th>DESCRIPTION</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>ANTI-ROTATION PIN</td>
<td>S.S.316</td>
</tr>
<tr>
<td>5</td>
<td>'O' RING</td>
<td>VITON</td>
</tr>
<tr>
<td>4</td>
<td>SLEEVE</td>
<td>S.S. 17-4 PH</td>
</tr>
<tr>
<td>3</td>
<td>MATING RING COMPOSITE</td>
<td>T.C.+TITANIUM</td>
</tr>
<tr>
<td>2</td>
<td>'O' RING</td>
<td>VITON</td>
</tr>
<tr>
<td>1</td>
<td>SEAL ASSY. (STATIONARY)</td>
<td>CARBON FACE</td>
</tr>
</tbody>
</table>
Life Testing of Final Prototype Units

The final prototype mechanisms incorporating special hardware items shall be tested as follows:

- The shut-off rod drive mechanism shall be tested for at least 5000 full drops and 2500 partial release tests (on line test) with inspection and preventive maintenance after every 500 drops and servicing after every 1000 full drops.

  The above mentioned drive mechanism shall also be tested for at least 2000 partial drops from various heights (for stepback) as control rod drive mechanism with inspection and preventive maintenance after every 500 drops.

- The adjuster rod drive mechanism shall be tested for at least 4500 cycles with inspection and preventive maintenance after every 500 cycles.

Status of Development

- Mark-I shut-off rod drive mechanism has been tested for 1000 drops and & Mark-II has been tested for more than 5000 drops for design validation and optimisation of scram characteristics and further testing is in progress.

- The adjuster rod drive mechanism is being tested for design validation.

- Qualification of dynamic shaft seals, spiral spring, rotary switchgear, potentiometer and reed switches is in progress.

- Manufacturing of final prototype mechanisms incorporating qualified hardware items is in progress.