Hot Cell Applications

Development and Installation of Remotely Operated Telescopic Camera System to View Pouring and Handling Operations

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Camera replacement underway in maintenance area

ABSTRACT

Indian Nuclear Power Programme has adopted a 'Closed Fuel Cycle' which involves reprocessing & recycling of Spent Nuclear Fuel and other wastes coming from nuclear reactors. This process involves use of special facilities, such as a 'Hot Cell', which is inaccessible to personnel due to the presence of high radiation levels. Any operation inside this cell is carried out in a remote manner by viewing through a Radiation Shielding Window (RSW) or a CCTV camera system. Exposure to high radiation fields causes browning of lenses and failure of camera electronics. To overcome this, a Telescopic Camera Assembly was designed & developed and subsequently installed inside the cell. This assembly includes a motorized rotating assembly for in-plane rotation and a motorized hoist assembly for vertical movement of CCTV camera pan-tilt assembly. This camera assembly will be exposed to radiation environment only during remote handling or vitrification operations in the Melter cell. This design minimizes radiation exposure by ensuring that the assembly will be rotated back into a lesser radioactive area (where fields are in mR) during the idle condition of the cell. This reduction in radiation exposure will ultimately enhance the life span, thus lowering the frequency of replacement of the camera assembly. Currently the system is being utilized in a campaign of vitrification operation of Waste Immobilization Plant(WIP), Trombay and is performing exceptionally well.

KEYWORDS: Hot cell, Melter cell, Remote viewing, Telescopic assembly, Vitrification, Planetary gearbox, CCTV camera

Introduction

Waste Immobilization Plant (WIP), Trombay, BARC [1] has been established with the mandate of liquid waste management generated by the Reprocessing Plant, which reprocesses the spent fuel discharged from Research Reactors. All remote handling gadgets inside the Hot Cell are operated by viewing through Radiation Shielding Window (RSW) or CCTV camera assisted monitors. A Telescopic Camera System was designed at WIP to view Melter cell operations. This motorized rotating telescopic assembly was primarily designed to view pouring operations and other remote handling activities inside the Melter cell. It was designed with two Degrees of Freedom (DOF) i.e. in-plane rotation (with fixed radius (r) & variable angle (θ) (i.e. polar motion) and vertical motion (tube-in-tube type motion in z direction). Additionally, a pan-tilt assembly (with two DOF) is also installed on the last tube, which holds a CCTV camera with connector assembly. This assembly has been installed on the partition wall between melter cell and maintenance area. Remote operations inside the cell using a commercially available camera is difficult because Charge Coupled Devices (CCD) have limited radiation life. Exposure to high radiation fields causes browning of optics and failure of camera electronics including the CCD sensors. This limited life, has necessitated limited exposure of the CCTV camera system to high radiation fields. This issue was solved by rotating the camera assembly after use, towards the maintenance area (where radiation field is mini scale in comparison to the melter cell). The melter cell operations can be viewed as and when required by rotating the camera assembly towards the melter cell using in-plane rotation through a wall cut out of 2m×1.5m. A schematic, showing the melter cell with telescope camera assembly has been shown in the Fig.1.

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Design Philosophy

Special Features

This assembly was designed with several special design features which are listed below

1) Material of Construction to suit the Hot Cell environment.

2) Remotely operable from outside the cell by viewing through RSW and mounted on the partition wall between melter cell and Parking Area of Vitrification Bay.

3) Specially designed in-planeplanetary gearbox with inbuilt

Fig.1: 3-D model of Melter Cell showing installation location of telescopic camera.

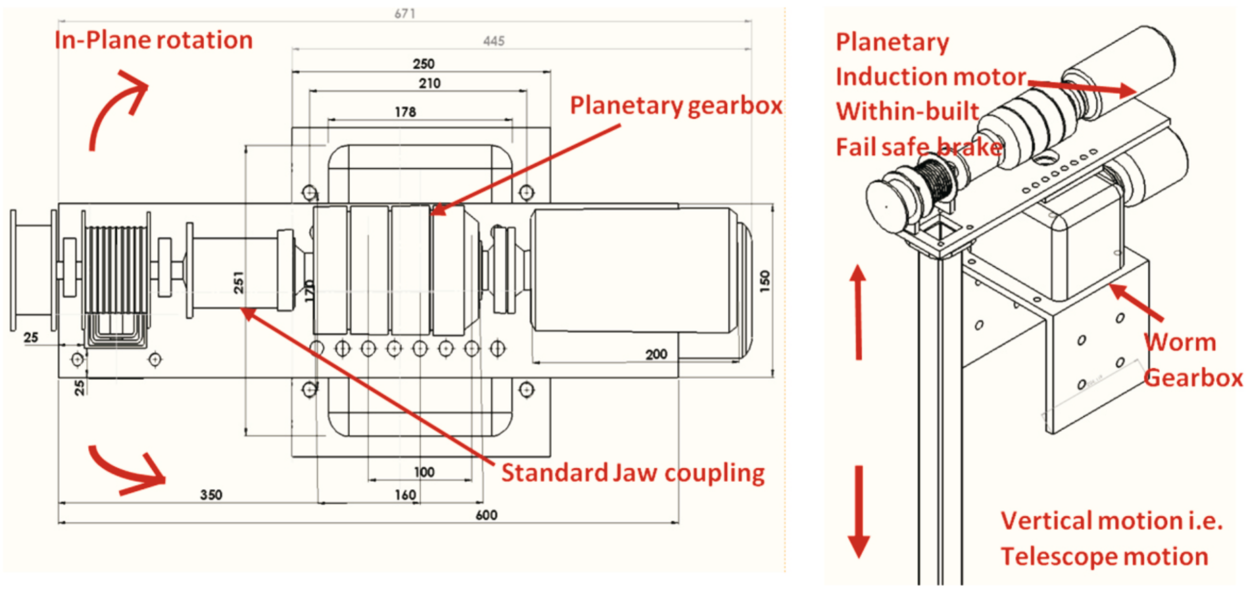

Fig.2: Telescope camera model with motions and major component.

AC Electromagnetic (ACEM) brake for vertical motion.

4) Telescopic vertical movement with adequate guiding supports and installation of limit switches to constrain all motion within required limits.

5) Specially designed vertical cable take up system to prevent cable entanglement.

6) Modular design and ease in replacement of cameras.

7) Material of Construction - Due to the highly radioactive & corrosive atmosphere within the cell, all structural & moving parts (sliding and rolling contacts) such as telescopic tubes, base plate, wire rope & rope drum are made of suitable grade of stainless steel (SS304). However, all gearbox units are housed in sealed enclosures to provide protection from contamination and corrosive environment.

Working Operation

The telescope consists of three tubes providing telescopic boom length of 4700mm and the collapsible length of 1700m. Tube size, limit switch and stopper location etc. are optimized in such a way to achieve the complete range of motion, as stated above. Camera with pan-tilt assembly is mounted on the bottom square tube for viewing purpose. Simultaneous operation of polar motion at different values of angle can enable it to reach to any position. All motions of the camera assembly have been shown in the Fig.2.

Design Methodology

The system has been installed inside the Melter cell which is already in operation and has a high radioactive field. Additionally, it has been mounted on partition wall where it has to travel through a wall cut out of 2m × 1.5m. This has been considered for calculation of collapsible length.

The size of whole system was optimized in a way so that exiting crane and girder mounted servo manipulator can freely travel through the cut out and should have sufficient clearance between telescope system and girder of existing crane and servo manipulator assembly. Mounting location on the partition wall has been shown in Fig.3. For complete viewing of the Melter cell this assembly is designed with four motions which are described as below.

Mounting location

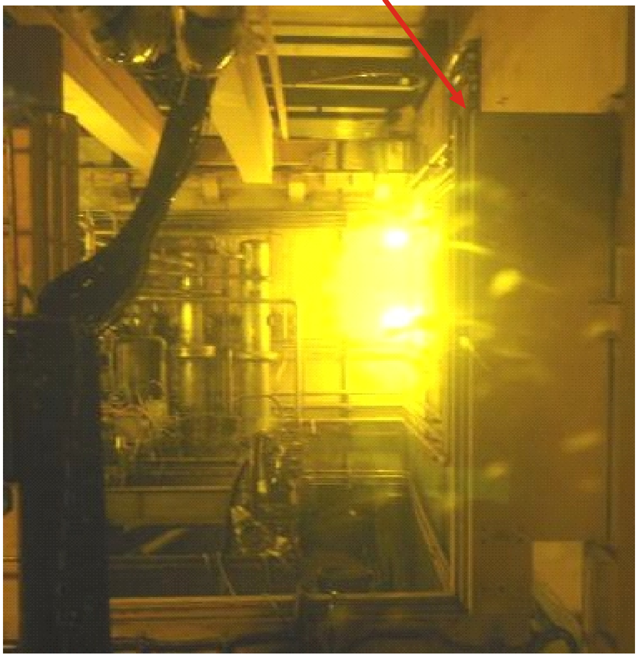

Fig.3: Mounting location inside the cell.

S.No.	Motion	Mechanism	
1.	In-plane rotation (with fixed radius (r) & variable angle (θ) polar motion)	Using Standard worm gearbox	200°(±100°) travel at 270mm radius
2.	Vertical (Telescopic motion)	Using customized In-planetary gearbox with flexible wire rope assembly	1.7m to 4.7m
3.	Pan & Tilt Motions	Standard pan-tilt Assembly	Pan=±180° & Rotation Tilt=±90

Telescopic Motion

Three square tubes of different sizes (were used for telescopic movement, where upper tube was fixed to upper rotating part as shown in the Fig.2 and lowest tube was tied to wire rope. Additionally, other arrangements were provided for precise linear motion in vertical direction and to avoid any un-intentional rotation. Two turns will always be on the rope drum at maximum extension of the tubes. Minimum Length of wire rope required = extended length of tubes + distance between topmost tube and pulley + no. of turns on rope drum × circumference of rope drum= 5.17m

Minimum breaking load of wire rope as per IS 3177 (1999) = $S \times Z_p \times C_{df}$ = 10KN; where S = Maximum rope tension, Z_p = Minimum practical coefficient of utilization, C_{df} = duty factor. SS304 wire rope having 4mm dia. with 6 x 19 construction has been selected with minimum breaking load of 38 KN.

Crushing Stress on Rope Drum =

$$\frac{\textit{Total mass on rope drum including camera structure}}{\textit{pitch} \times \textit{thickness below the groove of rope drum}}$$

$$\approx 340 \text{Kg/cm}^2$$

For bending stress, it is assumed that the entire wire load would act on the center of rope drum. This would result in safer design. The rope drum is supported on two bearings at a distance of 60 mm. The bearings are symmetrically placed with respect to center line of rope drum.

Maximum Bending Moment on Rope Drum =

$$\frac{\textit{load} \times \textit{distance between bearing}}{4}$$

Calculated Bending Stress on the Rope Drum $\approx$ **75kg/cm^2**

Total stress generated on the rope drum $\approx$ 412 kg/cm^2

Allowable Stresses on the rope drum as per IS3177

$$= \frac{\textit{Ultimate stress of the material}}{C_{df} \times C_{bf} \times C_{sf}}$$

C_{df} = Duty factor, C_{bf} = Basic stress factor, C_{sf} = Safety factor

Allowable stresses = 1000Kg/cm^2 total stress generated on the rope drum, Hence design of rope drum was safe.

Planetary Gearbox

A specialized foot mounted in-plane planetary gear box has been designed and fabricated with four stage reduction for this assembly to overcome space restraints. This gearbox has been designed primarily on the basis of two requirement which are listed as follows:-

1. Torque ($\approx$ 140kg-m)
2. High speed reduction (1:480) to achieve very low speeds

High torque was achieved in four stages using high grade material and spline shaped shafts instead of the usual key shapes. In every stage one sun gear was meshing with three planet gears mounted on the planet carrier which further meshes with another sun gear maintaining the same direction of rotation and this planet carrier will be connected to the output shaft of the gear unit. In the place of keys, splines in all shafts have been sued so that high torque can be transmitted.

The Motor was designed as per IS 3177: 1999 as per following expression.

$$\textbf{Minimum hoisting kW required} = \frac{M \times V \times C_{df} \times C_v}{6.12E \times C_{amb}} = \textbf{131.55 Watt}$$

Hence 0.25 HP of motor was selected.

Where:

M = Mass of the rated load and the wire rope in tonnes

V = hoisting speed in m/min

E = Combined efficiency of gears and sheaves

Where n = no. of gear pairs and m= total no. of rotating sheaves

C_v = Service factor, C_{df} = Duty factor, C_{amb} = Derating factor

Needle bearings have been selected for planet gears while deep groove ball bearings have been used to drive shafts. Enclosed Gears and shafts are made from EN 8 and EN 9 respectively. Four stages of planetary gearbox (speed reduction ratio of 1:480) with 0.25HP customized three phase brake induction motor (with totally enclosed fan cooling and IP55 protection) have been used for achieving low speeds of 3m/minute. Standard Jaw coupling has been used for transmission of rotation motion from the motor to rope drum assembly.

In-plane Rotation

Worm gearbox belongs to the cross axis drives where a very high reduction ratio can be realized in one single stage.

Customized worm gearbox was used to achieve very high-speed reduction for in- plane rotation (speed of 1rpm). This gearbox was powered using 0.5HP three phase brake induction motor (with totally enclosed fan cooling and IP55protection).

Fail safe Brakes

Fail safe brakes have been used in all motions. The brakes are designed to exert a restraining torque of minimum 50% greater than the maximum torque transmitted to the brake from the suspended load as follows:

Torque transmitted to brake =

$$\frac{\textit{Pitch circle trdia of rope drum } X \textit{ suspended load}}{4\ X \textit{ speed reduction ratio}}$$

CCTV Camera Assembly

The camera system consists of a CCTV camera, control cable, monitoring device (CCTV Monitor) and recording device (VCR/DVR). The camera has been installed on a pan-tilt assembly. This camera and monitoring device are connected through a 40m long multi-core composite cable. This cable carries video signal and other electronic signals. It is a combination of different types of specialized cables such as coaxial cables and low voltage carrying cables bundled in a singles pool. The camera control unit gives two video outputs; one for connection to monitor for display of images captured by camera, and, the other for recording. Standard Digital Video Recorder (DVR) is being used here for recording purpose.

Safety Features

In all motions after limit switches have been provided and during failure of these limit switches, mechanical stoppers have been used to avoid any unwanted accident and after reaching this position, control panel of an electric motor will get tripped. In this way, full assembly will be safe from accidental point of view. In failure of any component, this system can be lifted using existing in-cell crane of Melter cell without any manual intervention and can be shifted in maintenance area.

Challenges during Fabrication and Installation

Hook Arrangement

The hook was remotely installed inside the cell on the partition wall using an in-cell crane. As per design the in-plane motor was placed on the south side (on one side of the assembly) and the other motor assembly was placed towards the east direction (installed on worm gearbox). It was a challenging task to calculate the centre of gravity of the assembly and was found to be in the south-east direction. These factors were considered in the design of the hook (using 10mm diameter of rod). Also, the lifting eye was also located eccentrically (south-east direction).

Vertical Cable take up Assembly

The Vertical Cable Take-up Assembly was a design challenge as it had to prevent cable entanglement. Here cables (of 700mm length) in a single spool were fixed & mounted on the first telescopic tube (i.e. first stage). A Flexible cable drag chain (of 1.6m length) was used for extension/opening of second tube. Cables were routed and mounted on cable tray for extension of the third telescopic tube (i.e. last stage).

Location of Limit Switches

The entire telescopic assembly was retrofitted in an existing Hot Cell environment, with several pre-existingpath obstructions. Hence, two limit switches were located in the plane of rotation to restrict movement towards the melter cell and parking area. Two limit switches were also installed in vertical direction for extreme up & down locations. Location of vertical limit switches were selected to enable the following functions.

1. Optimal view of pouring and other remote handling operations

2. When not in use, the assembly will be rotated back through partition wall cut-out (of 2m depth), for parking in the maintenance area. The upper limit switches are located to accommodate the telescope in a desired collapsible condition. Locations of all limit switches were decided after taking into consideration the feedback of the operator.

Installation and Commissioning of Telescopic Camera System inside the Cell

Pre-installation Challenges

Prior to installation of this system, it was imperative to know the condition of the melter cell with respect to its background radiation & contamination level. Thus, a radiation survey was carried out and a few radiation hot spots were identified.

To overcome these hotspots, the existing portable shielding was modified, fabricated and installed at the installation site (i.e. partition wall) to avoid any radiation streaming to the working area.

Installation and Commissioning of Telescopic Assembly

Installation of assembly was carried out, subsequent to the radiation survey and decontamination. Installation work was categorized in the following stages.

1. External/Outcell testing of assembly for readiness.

Fig.4: Camera installed on last tube of assembly.

Limit switch details: Plunger type limit switches with metallic rollers were used.

Make	Siemens
Operating Force	20N (max.)
Limit Switch Actuator	Plunger type
Degree of protection	IP65
Contact Voltage AC	230VAC

2. Modification in local portable shielding to reduce radiation background.

3. Shifting & Insertion of telescopic assembly inside the cell.

4. Installation of assembly on partition wall using existing in-cell crane.

5. Cable routing inside the parking are a of HL bay.

6. Installation of control panel in operating area.

7. Remote operation of this assembly from a control panel (i.e. operating area).

Cable Routing

Cable routing (18m cabling) of this assembly was carried out inside the highly radioactive and contaminated environment of the cell. Hot cell cable routing was categorized in the following steps.

1. Cables (in PVC enclosure) were shifted inside the cell with Assembly.

2. Vertical routing of cables (for camera, pan-tilt assembly & bottom limit switch) on telescopic tubes using cable tray and cable drag chain.

3. Subsequent routing and mounting of all cables on the wall.

4. Removal of cables outside the cell through embedded plug and specially designed lead shielded plug (which was being used to avoid radiation streaming).

Commissioning

The Telescopic Based Camera System was subjected to rigorous testing by repeated remote operations from outside the cell, by viewing through RSW and CCTV camera monitors. All parameters for vertical motion and in-planemotion (including limit switches actuation etc.) were thoroughly checked. Subsequent to complete testing and commissioning activities, this assembly is currently being utilized in the ongoing campaign of vitrification operations.

Critical Operations Accomplished by Telescopic Based Camera System

The Telescopic based Camera System has been utilized for ten pouring campaigns where five no. of VWP canisters and one batch of vitrified product for Cesium pencil have been completed. Earlier, each camera life cycle was limited to a

Fig.5: Shifting and insertion of assembly inside the cell.

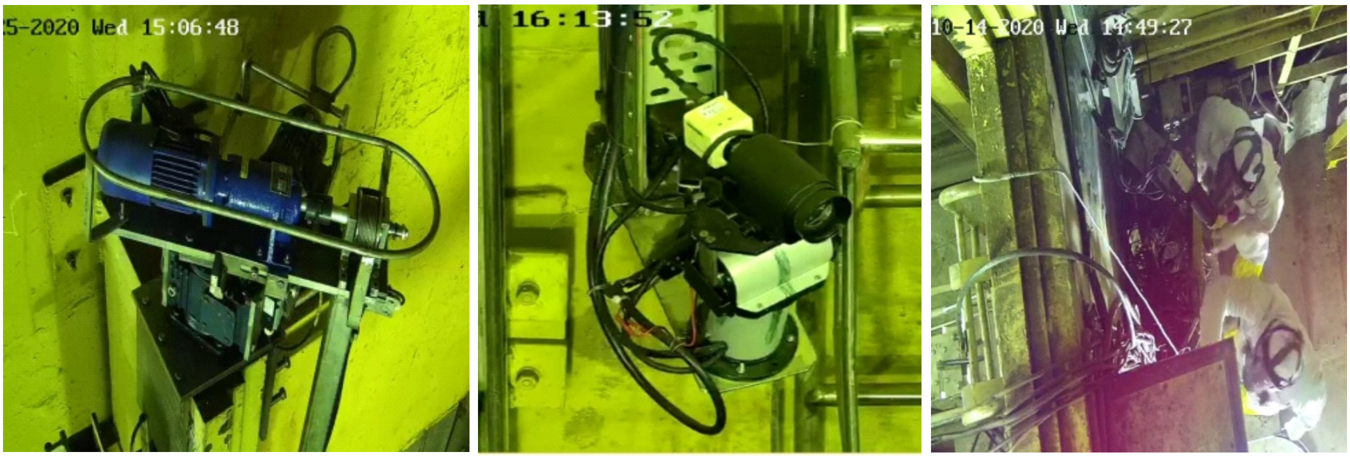

Fig.6: Telescope camera assembly inside the Melter cell.

single campaign. Other auxiliary operations such as weighing and several material handling activities were also completed using this system.

Conclusion

This system is nearing completion of almost 4 years of operating in a Hot Cell without any maintenance and high operational performance. It has been designed to enhance the life span of the conventional camera by taking into account several operational feedback and requirements of plant personnel involved in day to day operations of the Melter cell in the Vitrification bay of WIP, Trombay. This system has effectively increased efficiency of the camera life cycle by seven times. It has thus achieved several important targets of WIP, Trombay, by reducing man-rem exposure, giving cost benefits, lowered system down time by decreased frequency of change in cameras, and reduced disposal quantities of malfunctioned cameras thus decreasing radioactive waste.

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#Dr. C.P. Kaushik, Formerly Director of Nuclear Recycle Group, retired from service in February 2022.

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