Engineering design and development of shielding door and safety shutter for transfer line-3 tunnel of Indus accelerator complex

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Received 17 July 2010; accepted 19 August 2010

Indus accelerator complex houses two synchrotron radiation sources, Indus-1 and Indus-2. Electron beam from booster synchrotron is injected into Indus-2 through transfer line-3 (TL-3). In order to reduce the radiation coming from TL-3 through the door opening to Indus-1, to safe limit, a sliding shielding door has been developed. It is a close welded frame of mild steel with required thickness of shielding material in the form of interlocking lead bricks stacked inside. The door is suspended from an overhead I-beam attached to welded wall brackets, which are fixed to RCC wall using anchor fasteners. Pneumatic drive is used for moving the door. Radiation measurements carried out after the installation show substantial reduction in the radiation field at Indus-1 experimental hall. Another safety concern is the inadvertent transmission of electron beam from booster synchrotron to TL-3. For this purpose a safety shutter has been made. It comprises of a beam absorber made of high density alloy DENSIMET which can be moved in and out of electron beam path. Design, fabrication, installation and testing of sliding shielding door and the beam shutter have been described.

Keyword: Radiation shielding, Safety shutter, Synchrotron, Indus, Shielding door, Densimet

1 Introduction
Indus accelerator complex (IAC) houses 20 MeV microtron, 450 MeV/550 MeV booster synchrotron, 450 MeV synchrotron radiation source (SRS) Indus-1 and 2.5 GeV SRS Indus-2. 550 MeV electron beam from booster synchrotron is injected into Indus-2 through transfer line-3. The Indus-1 hall and TL-3 tunnel are separated by 1-meter thick concrete shielding wall. There is an opening (MS grill door) of 1200 mm (W) × 2000 mm (H) in the concrete shielding wall for equipment and personnel movement. During beam transport through TL-3, significant radiation field was observed in the beam line area (particularly HRVUV beam line) of Indus-1, due to beam stoppage on BPM-2 in the tunnel area. In order to block the bremsstrahlung radiation coming from TL-3 through the door opening, a sliding shielding door is designed and installed. Another safety concern during Indus-1 operation is the inadvertent transmission of electron beam to TL-3, which could lead to serious radiation accident if someone is working in TL-3 or Indus-2 ring area. In order to prevent this, a beam shutter (beam absorber) has been made and installed in the beginning of TL-3. Location of both these devices is shown in Fig. 1. In the present paper, mechanical design, fabrication, installation and testing details of the shielding door and safety shutter have been presented. Radiation survey results of the area after door installation are also covered briefly.

2 Development, Installation and Testing of Shielding Door

2.1 Shielding door design features
The shielding door weighing 34 kN is a top-hung horizontal sliding type of door. It is suspended from two commercially available flanged-wheeled trolleys, each of 50 kN capacity. Trolleys travel on standard I section beam ISMB 300 resting on wall brackets fixed to concrete shielding wall using high strength anchor fasteners. The size of shielding door is 1700 mm (W) × 2150 mm (H). The door frame is constructed by welding carbon steel square pipes of size 150 mm × 150 mm × 6 mm thick. The interlocking lead bricks are stacked inside the door frame and closed by 3 mm thick M.S. sheets on both the faces to prevent sidewise toppling of the bricks. Thickness of lead provided is 114 mm, upto 500 mm above and below the beam plane and 38 mm in rest of the area. Sufficient overlap on all the three sides is provided to have multiple scattering of the radiation emitted from the TL-3 and hence to reduce the dose to the HRVUV beam line area within safe limit. Assembly of shielding door is shown in Fig. 2.

2.2 Design and selection of components
Selection of I beam for wall brackets and rail is made on the basis of maximum stress and deflection criteria. The maximum allowable values are within limits as suggested by Indian Standard-IS 800. Shock
2.3 Drive system

Pneumatic drive is selected to move the door as, it is a clean and maintenance free system and also because of easy availability of compressed air in IAC. A double acting pneumatic cylinder of 125 mm bore and 1450 mm stroke with air cushioning at the ends is selected. Rubber buffers are also provided at both the ends to avoid over travel of door with impact. Speed of door movement is controlled using flow control valves and is kept low at 3 m/min. Piloted non return valves are provided for speed breaking. Door is operated manually using hand lever type valves.

2.4 Fabrication and quality assurance

Fabrication of door structure was done by M/s Vividh hi-fab in Baroda. A detailed quality assurance plan was made for the fabrication of the structure. It was ensured right from raw material procurement that the door is constructed as per the specification. All the welding was done by SMAW process by qualified welders using procedures qualified as per American Society of Mechanical Engineers (ASME) code. Proper fixtures were used to minimize distortion in
the structure. Dye penetrant tests were carried out to ensure defect free weld joints. The interlocking shielding bricks were made from Pb-Sb alloy for high strength and wear resistance, by casting process. To ensure internal soundness of casted bricks, destructive test was used. Few bricks were progressively machined on lathe to observe internal flaws.

2.5 Installation and testing

Shielding door is installed in a normally inaccessible area with paucity of space. Installation of supporting brackets each weighing 50 Kg and I beam weighing 200 Kg at a height of 2 to 3 m was a challenging job as they are to be mounted over transfer line-3 in the tunnel. A forklift truck with extended forks was used to move the above items across the TL-3. The supporting brackets were fixed to the concrete shielding wall with high strength anchor fasteners, using specified torque to achieve the rated load capacity. Holes for fixing the fasteners were drilled in the concrete wall using special hammer drilling process. After stacking of bricks, the door was tested for 25% over load. Photograph of shielding door is shown in Fig. 3.

2.6 Assessment of radiation level

Measurement of radiation level with the sliding shield door open and close condition was performed during beam transport through TL-3 to Indus-2 (Ref. 1). The radiation field during sliding door open and close condition is presented in Table 1. The table shows significant reduction in radiation field during sliding door closed condition in HRVUV Beam Line area, which shows the shielding effectiveness of the sliding door.

3 Design and Development of Safety Shutter

The beam absorber comprises of a 300 mm long×55 mm diam solid bar of DENSIMET (an alloy of 95% tungsten and 5% iron & nickel) having density of 18 gm/cm³. It is moved into the beam path using a pneumatic drive. The movement is carried out inside a rectangular vacuum chamber made of welded plates of stainless steel grade AISI 316L with end flanges of size DN160CF for connecting to TL-3.

<table>
<thead>
<tr>
<th>Location</th>
<th>Measured radiation field (µSv/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding door open</td>
<td>Sliding door closed</td>
</tr>
<tr>
<td>HRVUV Beam line area</td>
<td>3.0</td>
</tr>
<tr>
<td>MS grill door middle</td>
<td>4.4</td>
</tr>
<tr>
<td>MS grill door top</td>
<td>1.5</td>
</tr>
<tr>
<td>Top of concrete shielding</td>
<td>0.7</td>
</tr>
<tr>
<td>Near monochromator</td>
<td>0.1</td>
</tr>
<tr>
<td>On TL-3 tunnel wall</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 1 — Radiation field values

![Fig. 3 — Photograph of shielding door installed in TL-3 tunnel](image)
beam pipe. An edge welded diaphragm bellow provides vacuum sealing during movement of the beam absorber. Inside dimensions of chamber are: 163 mm (L)$\times$328 mm (W)$\times$197 mm (H). SS316L is selected as material of construction for ultra high vacuum requirements of low vapour pressure, lower specific outgassing rate, bakeability, weldability and high strength even at elevated temperature (desired for knife edge flanges). Pictorial view of beam shutter is shown in Fig. 4.

The actuation mechanism comprises of a central shaft, three guiding rods mounted parallel to each other, concentric with the bellow and a cylinder driven by compressed air. The position of absorber within the vacuum chamber is indicated by two reed switches mounted on the pneumatic cylinder. A provision has been made for operating the beam shutter manually, in case of unavailability of compressed air.

Operation of shutter is done remotely from control room. Shutter control system is a part of personnel protection system of Indus accelerator complex. It can be opened only in Indus-2 mode of operation whereas it remains closed in Indus-1 mode of operation, ensuring safety of workers at TL-3 and Indus-2 side. It is a relay-based hard-wired system which operates on 24 V DC power supply. It operates beam shutter remotely through an interface unit, which controls 230 volts mains used to actuate the compressed air solenoid valve. System enables the operation of beam shutter only after acquiring clearance from the interlock devices; any undesirable condition like high radiation level in transport line-3 areas during injection into Indus-1, failure of mains supply and low air pressure will close the beam shutter instantly.

4 Conclusions
The sliding shielding door and safety shutter for transfer line-3 have been successfully designed, fabricated, installed and tested. Radiation survey of the beamline area in Indus-1 hall shows the effectiveness of the shielding door. Both of these devices are operated regularly by the Indus operation staff and working safely and reliably.

Acknowledgement
The authors thank Shri C K Pithawa, Incharge IAC for his encouragement. Thanks are also due to Shri S C Joshi for continuous support and members of design review committee particularly Shri G Mundra, Jishnu Dwivedi and G Parchani for useful discussions and suggestions. Sincere efforts by Shri S S Parihar, B Oraon and S Jafar Ali are also acknowledged.

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