TDI Coating test at HiRadMat

Proposal 1605
HRMT-35

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Presentation Scope

- Introduction and Goals of HRMT-35-TDICOat
- Experimental Set Up
- Bill of Materials
- Operational Aspects
  - Preparation and Installation Phase
  - Lay-out
  - Operational Phase
  - Beam Required Information
- Activation and Cool-Down Storage
- Post Irradiation and Disposal
- Risk Analysis
- Conclusions
Introduction and Goals of HRMT-35-TDICOat

- After dismantling the TDI (10/01/2016), severe damage on the Ti coated surface on the hBN absorbing blocks was found.

- The absorbing blocks of the currently installed TDI are made out of Cu sputtered Graphite R4550.

- Given the past issues and the general uncertainties on coatings behavior when grazed by a high intensity proton beam, there is a high priority recommendation by the LHC Machine Committee (LMC#256) to test and validate the sputtered Cu performance under the worst impact conditions that the TDI could face.

- In order to gain important information for future beam intercepting devices, other coating configurations (by acting on the subtract and the thickness of the deposited layer) will be tested on low-Z materials such as R4550, 2D Tatsuno CFC and Molybdenum Graphite (MoGr).
Experimental Set Up

- The HRMT 28 tank and test bench will be used for this experiment
- Modifications will be performed on the jaw configuration in order to host up to 4 different absorbing materials and coating configurations:
  1. SGL Graphite R4550 TDI coating configuration with Cu coating
  2. SGL Graphite R4550 TDI coating configuration with Cu coating
  3. Tatsuno 2D CfC in a TDI configuration with Cu coating
  4. Molybdenum Graphite (MoGr) in a TDI configuration with Cu coating

- HRMT 28 assembly. Prior to the 72 bunches filling restriction, the experiment went exceptionally fine. First results are very promising.
Experimental Set Up

- **Upper Jaws Stroke**: +/- 30mm.
- **Lower Jaws Stroke**: +/- 30mm.
- **Tank Stroke (5th axis)**: +/- 60mm
- **Design is compatible with the installation on a standard HiRadMat table:**
Experimental Set Up

- Measurement methods will be:

  i. BPKG right upstream of the jaws in order to accurately monitor the beam position and verify the impact parameter.

  ii. Online visual inspection by means of 4-5 radiation resistant cameras.

  iii. Thermocouples PT100 to measure the temperature of the jaw frame and the absorbing blocks.

  iv. 2 BLMs to monitor beam losses during alignment of the beam and during grazing impact.
Bill of Materials

Left Absorbing Blocks

<table>
<thead>
<tr>
<th>Material</th>
<th>Total mass [kg]</th>
<th>Distance to beam axis [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite 4550</td>
<td>5.7</td>
<td>On Beam</td>
</tr>
<tr>
<td>Graphite 4550</td>
<td>5.7</td>
<td>On Beam</td>
</tr>
</tbody>
</table>

Right Absorbing Blocks

<table>
<thead>
<tr>
<th>Material</th>
<th>Total mass [kg]</th>
<th>Distance to beam axis [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tatsuno CFC</td>
<td>4.6</td>
<td>On Beam</td>
</tr>
<tr>
<td>Molybdenum Graphite</td>
<td>1.8</td>
<td>On Beam</td>
</tr>
</tbody>
</table>

Main systems and components

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Estimated weight [kg]</th>
<th>Distance to the beam axis [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum Tank</td>
<td>Stainless Steel 304L</td>
<td>363</td>
<td>112</td>
</tr>
<tr>
<td>Jaw housing and stiffener</td>
<td>Stainless Steel 304L</td>
<td>71</td>
<td>33</td>
</tr>
<tr>
<td>Cradle and 5th axis</td>
<td>AW-6082 T6</td>
<td>132</td>
<td>160</td>
</tr>
<tr>
<td>Mechanical Tables</td>
<td>AW-6082 T6</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>LVDTs axis</td>
<td>Brass</td>
<td>0.1</td>
<td>290</td>
</tr>
<tr>
<td>Plug-in</td>
<td>AW-6082 T6</td>
<td>32</td>
<td>215</td>
</tr>
<tr>
<td>Support Feet</td>
<td>AW-6082 T6</td>
<td>77</td>
<td>600</td>
</tr>
<tr>
<td>Vacuum Windows</td>
<td>Beryllium</td>
<td>0.012</td>
<td>On Beam</td>
</tr>
<tr>
<td>Optical Windows</td>
<td>Rad-Hard Glass</td>
<td>1.5</td>
<td>80</td>
</tr>
<tr>
<td>Bellows</td>
<td>Stainless Steel 316L</td>
<td>0.5</td>
<td>78</td>
</tr>
</tbody>
</table>
Operational Aspects

- **Preparation & Installation Phase:**

  1) **Experiment Integration and Assembly – estimated time ~ 4 weeks**
     - Manufacturing of the 4 new designed jaws (housings and back stiffeners) by EN/STI
     - Purchasing, conditioning and coating of the absorbing blocks by EN/STI, EN/MME and TE/VSC
     - HRMT-28 tank, collimator feet, plug-in, cradle, 5th axis, instrumentation and equipment to be re-used after cool-down phase is effective, and jaws extracted from the tank at b. 867 RP area.
     - All parts of HRMT-35 assembled, instrumented and tested at b. 867 RP area and at b. 272.
     - BPKG support and jaw with respect to the tank alignment in Metrology Lab.

  2) **Integration in SPS-BA7 – estimated time ~ 3 weeks**
     - Integration of the experimental tank interface plate on to the HRMT lifting table.
     - Alignment cross-check, HRMT-35 assembly with respect to the HRMT lifting table.
     - Integration of the electrical connectivity (hyper tack).
     - First testing of the remote control system.
     - Connection and installation of the rad-hard cameras to the test-bench.

  3) **Installation in TNC estimated time ~ 1 week**
     - Transported to the TNC HiRadMat area via a trolley transport system, vertical lift and then remotely controlled crane.
     - Electrical connection of the cables for the rad-hard cameras. Additional new cables are required (+3), no technical complications.
     - Electrical connection of the vacuum pump via the TNC/TT61 holes.
Operational Aspects

- Lay-out

TT61 Side

TNC Side
Operational Aspects

- **Operational Phase**

**1) Alignment Phase (one per vertical coupled jaws)**

1) Establish beam position with BPKG and collimator jaws retracted.
2) Set up interlock thresholds.
3) Copy settings to high intensity cycle.
4) Set up collimator motion towards beam (12 bunches shots) by steps and correlate jaw position with beam losses.
5) Establish grazing impact position parameter with beam losses
   - 0.5 sigma steps with nominal bunch: scan gap. [Small gap]
Operational Aspects

- Operational Phase

2) Experimental Phase (one per vertical coupled jaws)

1) Move collimator jaws out: calculate jaw setting with defined beam center.
2) Verification with fast 12 bunches shot: check trajectory.
3) Move in lower jaw to grazing impact position parameter.
4) Verification shot with 12 bunches shot. Check beam loss signal, check position on BPKG (Vertical Alignment accuracy: +/-0.5σ).
5) 1st out of maximum 4 beam shots of 144 bunches. After each shot, the jaw is moved in by 0.5σ steps.
6) 1st out of maximum 20 beam shots of 288 bunches. After each shot, the jaw is moved in by 0.5σ steps.
7) Move out lower jaw to retracted position.
8) Move in upper jaw to grazing impact position parameter.
9) Verification shot with 12 bunches shot. Check beam loss signal, check position on BPKG (Vertical Alignment accuracy: +/-0.5σ).
10) 1st out of maximum 4 beam shots of 144 bunches. After each shot, the jaw is moved in by 0.5σ steps.
11) 1st out of maximum 20 beam shots of 288 bunches. After each shot, the jaw is moved in by 0.5σ steps.
12) Move out upper jaw to retracted position.
13) Move 5th axis to start alignment phase with the other set of vertically coupled jaws.
14) Repeat operational procedure.
Operational Aspects

Beam Required Information

Beam time:

- Beam based alignment time estimation is around 4 hours in total.
- Maximum 24 beam pulses are foreseen per jaw, (4*144 bunches + 20*288 bunches). Time estimation per jaw is 4 hours.
- Grazing impact on 3 different surface points on Carbon based Cu coated jaws.
- Time estimated between shots is 60 seconds, in order to allow inspection of acquired monitoring data and cool-down.
- Once room temperature is reached, the concerned jaw will be moved horizontally to provide a new surface for consecutive shots.

Total Operational time estimation is 20 hours

The accuracy of the beam parameters is a critical aspect on this experiment. Furthermore, from the beam base alignment check phase with 12 bunches to the grazing impact operation with 144 and 288 bunches, all shots must come from the same magnetic cycle. Optics are still under discussion for HRMT-28.
Simulations were performed with the following assumptions and baselines:

- The full total of 96 high intensity received grazing impacts at 0.5σ in one jaw in exactly the same position, thus maximizing the activation for both the jaw and the downstream tank.

- Highest activated element will be the downstream flange. Values of the dose rate of HRM28, on the downstream flange (impacted on the 07/04/2016):
  - Measured 07/06/2016: debit de dose contact = 210 microSv/h, 30 microSv/h @ 40 cm
  - Measured 27/06/2015 : debit de dose contact = 160 microSv/h, 25 microSv/h @ 40 cm

<table>
<thead>
<tr>
<th>Cooling time</th>
<th>Residual dose jaw</th>
<th>Residual dose tank</th>
<th>Residual dose 0.4m from tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>7900mSv/hr</td>
<td>2300mSv/hr</td>
<td>21mSv/hr</td>
</tr>
<tr>
<td>1 day</td>
<td>7mSv/hr</td>
<td>13mSv/hr</td>
<td>0.6mSv/hr</td>
</tr>
<tr>
<td>1 week</td>
<td>2mSv/hr</td>
<td>4mSv/hr</td>
<td>80μSv/hr</td>
</tr>
<tr>
<td>1 month</td>
<td>0.6mSv/hr</td>
<td>0.9mSv/hr</td>
<td>23μSv/hr</td>
</tr>
<tr>
<td>6 months</td>
<td>85μSv/hr</td>
<td>0.1mSv/hr</td>
<td>5μSv/hr</td>
</tr>
<tr>
<td>1 year</td>
<td>26μSv/hr</td>
<td>40μSv/hr</td>
<td>1μSv/hr</td>
</tr>
</tbody>
</table>
Activation and Cool-Down Storage

- After the experiment, the vacuum pump will be remotely switched off, and a valve placed at the pump inlet remotely closed.

- The experimental set-up will need to remain at the experimental area for \(~1\) month for radiation cool-down. Then, fast disconnection of services not included in standard HRMT table (<1 mSv/h tank wall).

- Remote transport with the crane to the cool-down storage area downstream in TNC tunnel.

- 4 months of cooling at the storage area downstream in TNC tunnel, radiation dose rate drops to levels below 200\(\mu\)Sv/h at contact with the tank walls.
Disconnection by hand of cabling not integrated on HRM Table:
- 5 x Rad-Hard camera cables
  - Each Disconnection: 15 s
  - Total Exposure Time: 3 min
  - Radiation Dose: 1 month (at contact with tank wall), <1 mSv/hr
  - Total Radiation Dose < 50 μSv
**Post Irradiation and Disposal**

- **Procedure:**

  1. Full assembly after 1 months of storage at TNC. Transport all assembly to BA7 surface.

  2. Disassemble at BA7 surface of the tank, BPKG and HRM table. HRM table stays at BA7, the rest are transported to radioactive to 867 RP bunker.
Procedure:

3. Opening of the cover of the tank at 867 radioactive workshop.
   Time needed: 2 min
   Resources needed: 3 pacs
   Radiation Dose: < 200 μSv/hr
   Total Radiation Dose Taken < 7 μSv (per pac)
Post Irradiation and Disposal

- **Procedure:**

4. Dismounting and extraction of the jaws at 867 radioactive workshop.
   
   **Time Needed:** 5 min per jaw
   **Resources needed:** 2 pacs
   **Radiation Dose:** < 200 μSv/hr
   **Total Radiation Dose:** < 20 μSv (per jaw per pac)
Post Irradiation and Disposal

- **Procedure:**

5. Disassembly of the jaw components and extraction of the absorbing blocks at 867 radioactive workshop.
   - Time: 20 s/screw (6 screw tountighten) + 2 min target extraction
   - Resources needed: 1 pac
   - Radiation dose: < 200 μSv/hr
   - Total time per Jaw ≈ 4 min
   - Total Radiation Dose: < 60 μSv (per jaw per pac)
Post Irradiation and Disposal

- **Post-irradiation test foreseen:** (timing details to be agreed with HSE/RP, analysis that are not performable in a radioactive workshop need to be performed in a delimited (by RP) “radioactive zone”)
  - Metrology measurements *(Bldg. 72 Metrology)*
  - Ultrasound tests *(CERN, MME Lab)*
  - Microscopy analysis *(CERN, MME Lab)*
  - Electrical resistivity measurements *(CERN, BE Lab)*

- **This results will be compared with the results of the tests performed before the experience on the absorbing blocks.**

- **Results will be key to validate not only the Cu coating, but the carbon based material itself as substrate.**
## Risk Analysis

<table>
<thead>
<tr>
<th>Event</th>
<th>Description</th>
<th>Hazard</th>
<th>Measures/Precautions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installation and Assembly</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual Handling</td>
<td>Work to be done during the assembly</td>
<td>Injury due to lifting heavy objects</td>
<td>Several handles for single component, to facilitate the lifting by multiple people (e.g. tank door). Modular design easy to mount and dismount Use of crane/lift</td>
</tr>
<tr>
<td>Pre-existing activation of the experimental area and HRMT-28 tank</td>
<td>Exposure during the assembly and installation phase</td>
<td>Ionizing radiation</td>
<td>Cooling down times under control and minimizing time for the operations, both in surface and at TNC</td>
</tr>
<tr>
<td>Vacuum</td>
<td>Vacuum inside the tank</td>
<td>Rupture of the Window</td>
<td>Calculations done to choose the needed thickness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive bow</td>
<td>Calculations done to choose the needed thickness</td>
</tr>
<tr>
<td>Test bench lift</td>
<td>Positioning on Position 2 in TNC</td>
<td>Fall of heavy loads</td>
<td>Verification Crain maximum lifting capacity &gt; total test bench weight</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test bench transport</td>
<td>The test-bench needs to be transported from BA7 to TNC</td>
<td>Fall of heavy loads</td>
<td>Slower transport and verification of maximum capacities</td>
</tr>
<tr>
<td>Transport</td>
<td>Vibration occurring during the transport</td>
<td>Loosing of jaw/instrumentation alignment</td>
<td>After the pre-alignment on the BA7 surface another one is foreseen in TNC with the pilot beam. Adding dumpers on the trolley.</td>
</tr>
</tbody>
</table>
## Risk Analysis

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<thead>
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<th>Hazard</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental Phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire</td>
<td>Ignition of components</td>
<td>Potential release of radioactive material</td>
<td>All the component are under vacuum and the max temperature for the target is much below the max service temperature (under vacuum). Risk of ignition is totally eliminated</td>
</tr>
</tbody>
</table>
| Experiment diagnostic | Measurements to be done in a high radioactive area | High activate environment | Remote diagnostic only  
Electronic devices to be placed on the bunker (TT61) protected by the shielding |
| Overheating of target samples and Cu coatings | Overheat of target due to successive proton beam impacts | Melting or vaporization of the targets and Cu surface | Close monitoring of absorbing blocks and coated surfaces temperature  
>60 sec period between two consecutive pulses in the same target (possibility to increase depending on T)  
Presence of the 5th axis motorization |
| Release of radioactive material | Leakage of radioactive material outside the tank due to fragmentation/vaporization of targets and containment failure | Radioactive contamination of the area | Monitoring of targets temperature to avoid vaporization  
Vacuum in the Tank  
HEPA H14 (or greater class) filter upstream the vacuum |
| Beam misalignment | Large beam misalignment producing impact of the proton beam with the tank walls or internal structures | Damage of tank and internal structures | Alignment done using precise beam monitoring system  
Low density material – Aluminium and graphite-employed for internal structures |
## Risk Analysis

<table>
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<tr>
<th>Event</th>
<th>Description</th>
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<th>Measures/Precautions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dismounting and Extraction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation exposure during the disconnection of cable</td>
<td>After the experiment some cables need to be disconnected manually from the HRM table</td>
<td>Exposure to ionizing radiation</td>
<td>Check first the level of radiation. Minimizing (via the help of an operating procedure) the time for the operation in TNC with test before the actual experiment.</td>
</tr>
<tr>
<td>Activation of the tank and jaws</td>
<td>Extracting the irradiated materials</td>
<td>Exposure to ionizing radiation</td>
<td>Design made to facilitate the jaw extraction and reducing the dismounting time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tools for dismounting procedure further from the activated components</td>
</tr>
<tr>
<td><strong>Post Irradiation Phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metrology tests</td>
<td>Radiation exposure during PIE of irradiated targets</td>
<td>Exposure to ionizing radiation</td>
<td>PIE carried out only after RP greenlight in a delimited “radioactive” are or radioactive workshop. All the PIE will be performed before and after on the target materials. An operating procedure will be written and they will be performed in a “radioactive” delimited (by RP) area.</td>
</tr>
<tr>
<td>Ultrasound tests</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Microscopy Inspections</td>
<td></td>
<td></td>
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<tr>
<td>Micro tomography tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasound tests</td>
<td></td>
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</tr>
</tbody>
</table>
Conclusions

- The experiment proposed will allow to test and validate the sputtered Cu performance on different interesting substrates.

- The experiment propose will allow to gain important information for future beam intercepting devices, such us TDISs, TCPPs and TCSPMs.

- The accuracy of the beam parameters is a critical aspect on this experiment.

- Simulations on expected radiation levels were done (detailed information in the Safety File) and the conclusions are acceptable for the proposed procedures.

- Visual on-line Monitorization and Post Irradiation Analysis will be able to detect material and Cu coated surface damage and the extent of it.

- Safety aspects represent a major priority during all the phases of the experiment. The measures and precautions taken should control the possible risks and hazards.

- 4 months cool down period in TNC will be sufficient for residual dose rate to fall down <200 μSv/h at contact with the tank wall.
Thank you!