Mu2e Remote Handling Design

Mike Campbell
L4 Manager, Target Remote Handling
11-17-2015
Outline

1. Requirements

2. Remote Handling Modules Overview

3. Target Exchange Sequence of Operation

4. Detailed Review: Remote Handling of the Target and Anti-Proton (AP) Absorber
   a) Design of Kinematic Mounts to achieve accurate location
   b) Design of Target and how mounted inside HRS bore
   c) Design of RH module and how will handle the Target
   d) Design of AP Absorber and how mounted inside HRS bore
   e) Design of RH module and how will handle the AP Absorber

5. Design Features re: Contamination Control and Error Handling / Recovery

6. Prototyping Plans

7. Next Steps
Requirements

Remote Handling Requirements Doc:

1. Overview

The Mu2e [1] Remote Handling System will be used to replace the production target and other secondary devices. This document describes top-level requirements for this device.

2. Requirements

2.1. General requirements

2.1.1. The remote handling shall provide safe handling methods, equipment, and facilities to support target hall component replacement and short-term storage.

2.1.2. The remote handling shall incorporate ALARA (As Low As Reasonably Achievable) principles into equipment and procedures.

2.1.3. The remote handling shall be integrated into the infrastructure of the complex both underground and above ground.

2.2. Devices

2.2.1. Vacuum Window(s): Remote Handling systems shall be designed to replace the vacuum window(s) from the production solenoid remotely. All activities must be performed to minimize radiation exposure to workers.

2.2.2. Production Target: Remote Handling systems shall be designed to remove the production target from the production solenoid remotely. All activities must be performed to minimize radiation exposure to workers. This activity must be performed in less than one month, and may occur on a yearly basis.

2.2.3. Anti-Proton Absorber: Remote Handling systems shall be designed to remove the anti-proton absorber from the production solenoid remotely. All activities must be performed to minimize radiation exposure to workers.

2.2.4. 

2.3. Radiation Considerations

2.3.1. Prompt Radiation: Shielding in the Remote Handling room and surrounding areas shall be sufficient to Target Hall equipment from prompt radiation. This requirement shall be evaluated in integrated MARS model of the Target Station.

2.3.2. Residual Radiation: Shielding shall be required to protect workers in the Target Hall during servicing scenario from residual radiation. This requirement shall be evaluated in integrated MARS model of the Target Station.

2.3.3. Water Activation: Activation of surface and ground water shall be less than the limits established in the FRCM [4, Table 3-1].

2.3.4. Air Activation: Air activation in the target hall after the cooling period shall be less than the limits established in the FRCM [4].

Anti-Proton Absorber Requirements:

Upstream Antiproton Absorber

Location: 10 cm upstream of face of 1° collimator [1], z (face of collimator in mu2e coordinates) = 4044 mm [2]

Material: 250 μm of Al [1], tolerance on thickness, my guess +/- 25 μm based on slide 3 [1]

Diameter: 320 mm [1] suggested size used in simulation

HRS bore=40 cm, Collimator bore=30 cm minimum size, Dave Pushka requests 2.5 cm minimum clearance for pumping, so ~ 35 cm maximum size

Mounting Hardware: Should be outside aperture of collimator
Remote Handling Modules Overview

1. Two Modules:
   - Window Module - to remove the window, install new one
   - Target Module - to remove the Target, install new one (also the AP Absorber)

2. Both modules incorporate a cask for the object being handled

3. Modules planned to be stored in the RH room
   - But machine control system (including motors, etc.) can be removed
4. Window Module:
   • Handles the main window (located on center of endcap)
   • Will also handle the other 2 smaller off-center windows (beam exit, extinction)
   • Will incorporate X, Y, Z servo positioning axes, plus pneumatic motions to:
     - Remove bolt circle, remove window, place into top-loaded cask below
     - Then later: place new window, tighten bolt circle, making vacuum seal
   • Has lower contamination risk
   • Was decided to design this AFTER first addressing the higher risk Target module
   • Design concept exists but detailed design not complete enough to review yet
5. Target Module:
   - Handles two radioactive objects: the Target and AP Absorber
   - Includes a contamination-containment box that the object is pulled back into
   - Uses a long single arm to reach out 13’-6” to Target, located inside HRS
   - Uses one level of telescoping arm motion to reach out 20’-4” to AP Absorber
   - The EOAT (End Of Arm Tooling) is automatically de-coupled from the end of the arm and left in the containment box along with the object being handled
   - Has higher contamination risk, thus was decided to design this first
   - Therefore – this is what we will be focusing on for this review
Target Exchange Sequence of Operation

Room Layout
Target Exchange Sequence of Operation

1. Move Window Module into position under the overhead monorail crane
2. Use monorail to place Window Module onto the Lift / Transfer Cart
3. Position Window Module at Mock-up Frame. Do practice runs as needed to confirm module is working properly.
4. Return Window Module to position under monorail
5. Return Window Module to parked position in the RH room
6. Move Target Module into position under the overhead monorail crane
7. Use monorail to place Target Module onto the Lift / Transfer Cart
8. Position Target Module at Mock-up Frame. Do practice runs as needed to confirm module is working properly.
9. Return Target Module to position under monorail
10. Return Target Module to parked position in the RH room
Target Exchange Sequence of Operation

10. Return Target Module to parked position in the RH room

>>> Now ready to begin exchange process for the real target . . .
11. Place Window Module onto cart
12. Place window cask onto the cart using the monorail
13. Open sliding shield door
14. Window Module is transported into the target hall by the cart, lifted, and set down onto kinematic mounts in position behind the PS (Production Solenoid)
15. Window Module performs it’s task: removes bolt circle, removes window, places down into top-loaded cask
16. Return Window Module to position under monorail
17. Close the sliding shield door
18. Place lid onto cask using the monorail. Then people approach cask and manually bolt lid down
20. Return Window Module to parked position in the RH room
21. Place Target Module onto cart
22. Place target cask onto the cart using the monorail
23. Open sliding shield door
24. Target Module is transported into the target hall by the cart, lifted, and set down onto kinematic mounts in position behind the PS.
25. Target Module performs it’s task: removes spent target, leaves target and interface tooling in contamination-containment box, places box down into top-loaded cask.
26. Return Target Module to position under monorail
27. Close the sliding shield door
28. Place lid onto cask using the monorail. Then people approach cask and manually bolt lid down
>>> Spent target removal now complete
Next: install new target and window
30. Manually load new interface tooling and new target to the end of the long arm of the Target Module
31. Open sliding shield door
Target Module is transported into the target hall by the cart, lifted, and set down onto kinematic mounts in position behind the PS
33. Target Module performs it’s task: installs new target
34. Return Target Module to position under monorail
35. Close the sliding shield door
36. Return Target Module to parked position in the RH room
37. Place Window Module onto cart
38. Manually load new window to the Window Module
39. Open sliding shield door
40. Window Module is transported into the target hall by the cart, lifted, and set down onto kinematic mounts in position behind the PS
41. Window Module performs it’s task: installs new window, tightens bolt circle to make vacuum seal
Target Exchange Sequence of Operation

42. Return Window Module to position under monorail
43. Close the sliding shield door
44. Return Window Module to parked position in the RH room
Target exchange now complete
Detailed Review: Design of Kinematic Mounts

Pair of large cylinders locate Y and Z, hold weight

Small crossing cylinder locates X

V-blocks at front of module base frame

3-point mount: motor / leadscrew extending motion axis sets tilt angle based on sensor feedback

View looking up through floor
Detailed Review: Design of Target and Mount

**Target Assembly by RAL**

- **3X spring-loaded push/turn latches**
- **2X grip handles**
- **Outer ring (a.k.a. the “bicycle wheel”)**

**1/8” radial clearance to HRS bore**

**3X mounting ears Inside the HRS**

Latch prior to insertion
- **Bronze rollers**
- Needs to be pushed-in and turned 90 degrees

Latch after insertion
- Provides location & clamping pressure
Detailed Review: Design of RH Target Module and how handles the Target

**RH Target Module**

- AL extrusion frame w/ AL tabletop
- Lift / transport cart
- 4X cart columns
- Long arm for reaching the Target
- Has telescoping inner for reaching AP Absorber
- EOAT (End of Arm Tooling)
- Contamination Containment Box (yellow)
- Cask
**RH Target Module**

- Long arm for reaching the Target
- AL extrusion frame w/ AL tabletop
- Has telescoping inner for reaching AP Absorber
- Contamination Containment Box (yellow)
- EOAT (End of Arm Tooling)
- Cask

Cart omitted for clarity. Same for all future slides.
Detailed Review: Design of RH Target Module and how handles the Target

Permanent portion of the EOAT
Contains all of the pneumatic actuators

Interface Tooling – disposable, gets discarded with the Target

Target Assembly (a.k.a. the Target)
Detailed Review: Design of RH Target Module and how handles the Target

**Interface Tooling**

- **2X expanding gripper fingers** to engage grip handles on the bicycle wheel. Spring-loaded to the out position (gripping target)
- **4X expanding rollers** to pilot into I.D. of the HRS. Spring-loaded to the out position
- **3X latch pushers** - To push / turn spring-latches on the bicycle wheel. Engaged from the rear by pneumatic actuator (not spring-loaded)
- **THK linear bearings** Typical
- **Scraper blade** - Moves down to wipe-out bottom of HRS bore as spent target is being extracted. Spring-loaded to the up position
Detailed Review: Design of RH Target Module and how handles the Target

- Pins thru back of plate for pneumatic actuators to engage
- Rollers out in front of the bicycle wheel. Leading the way into the HRS bore

- Clearance for debris as the EOAT approaches the spent target
- Dovetail grip handle: Interface tooling is held & released here by mating gripper
Permanent Portion of the Target EOAT

4X air cylinders actuate expanding rollers in/out

2X air cylinders (at 3 and 9 o’clock positions). Actuates gripper fingers in/out for holding the target

Air cylinder moves this bar up/down from behind (hidden from view). Actuates the scraper blade

Borescope – not designed-in yet but will be there
Detailed Review: Design of RH Target Module and how handles the Target

- Permanent Portion of the Target EOAT
  - Dovetail gripper fingers for holding the Interface Tooling from behind by its’ mating grip handle. Has THK linear bearings and pneumatic rotary actuator (hidden from view) with cam for open/close. Spring-loaded to closed position.

- 3X Latch-actuator mechanisms:
  A) Air-slide for push motion
  B) Pneumatic rotary actuator for 90 degree rotate motion
  C) Air cylinder for latch/pull motion
  D) Slotted tool for engaging back of latch pushers on Interface Tooling
Detailed Review: Design of RH Target Module and how handles the Target

Arm with permanent portion of Target EOAT

Interface Tooling

Target

All 3 put together
Detailed Review: Design of RH Target Module and how handles the Target

Arm with permanent portion of Target EOAT

Interface Tooling

Target

Target EOAT
Detailed Review: Design of RH Target Module and how handles the Target

- Dovetail grip handle on top
- Contamination containment box
- Hole where arm passes through
- 2X Bullet-nosed hanger rods
- Target and Interface Tooling inside
- Arm retracted thru box - getting ready to de-couple
- Arm decoupled - then full retract
Detailed Review: Design of RH Target Module and how handles the Target

**RH Target Module**

Vertical servo/screw linear axis with dovetail gripper to hold containment box from above. 37” downstroke places box into cask.

Bridge structure holds containment box from above. To have servo/chain drive for 48” horizontal motion (12” forward + 36” retract).

THK linear bearing rails

Long arm – to have servo/chain drive for 13’-6” in/out motion
1. Starts with Target Interface Tooling inside the containment box and mounted to the end of the long arm
2. Containment box and arm move 12” forward together – enclosing the vacuum window port. Box is above the cask and still behind the cask front wall.
3. Arm extends approx. 12’-6” to reach spent target inside the HRS bore
4. EOAT motions release target from mount (grip target by its’ handles, individually push/turn/pull-back each of the 3 latches), retract 1”, then lower scraper blade
5. Retract arm – pulling Interface Tooling and Target back into containment box. Interface Tooling pilots onto hanger rods inside box.
6. Retract arm and containment box 12”
7. De-couple from Interface Tooling by opening dovetail gripper and retracting arm approx. 20” to full retract position
Detailed Review: Design of RH Target Module and how handles the Target

8. Lower containment box 27” to get top of box below window flange
Detailed Review: Design of RH Target Module and how handles the Target

9. Move containment box forward 12” again to line up top of box with cask interior
10. Lower containment box into cask (approx. 10”). Open dovetail gripper, releasing containment box
Detailed Review: Design of RH Target Module and how handles the Target

Target Exchange Sequence

11. Move box gripper up 37” to full vertical retract position
12. Move box gripper back 48” to full horizontal retract position – clearing space above cask. >>> Spent Target extraction process complete
13. New Target install: no containment box and no cask, new Interface Tooling & new Target pre-loaded on end of arm. Extend arm, EOAT motions install new Target
Detailed Review: Design of Anti-Proton Absorber and Mount

Current plan:

- 0.010” AL foil
- 3X pegs in front: Grip handles
- 3X pegs in back: Mounting hooks
- Stainless Steel Mounting ring
- 3X welded-on mounting tabs inside HRS bore
- 3X mounting brackets allow ring alignment inside bore when bolted-on
- 15mm lift releases from mount

AP Absorber mounted position

Dimensions:
- 10’-7” (~3.2m)
- 6’-8” (~2m)
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

AP Absorber EOAT

Telescoping arm mounted inside main arm

Permanent portion of the EOAT
Contains all of the pneumatic actuators

Interface Tooling – disposable,
gets discarded with the AP Absorber
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

Interface Tooling

4X rigidly mounted rollers pilot into the HRS bore

Air cylinder to engage here from the rear. Will provide 15mm lift motion (not spring-loaded)

Horizontal THK linear bearings for grip motion

Vertical THK Linear bearings

3X pairs of gripper fingers grab the AP Absorber by the grip handles. Fingers tied together mechanically so that a single pneumatic actuator (engaging from the rear) can open/close all 3 sets. All spring-loaded to the closed position
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

Rollers behind the AP Window but will still lead the way into the tapered section of the HRS bore since at a larger radius

Cam followers thru back of plate for pneumatic actuators to engage

3X sets of cutouts in the AP Absorber and EOAT clear the target mounting ears as it passes thru the HRS bore

Dovetail grip handle: Interface Tooling is held & released here by mating gripper
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

Permanent Portion of the AP Absorber EOAT

Borescope – not designed-in yet but will be there

Air cylinder provides 15mm lift motion

Dovetail gripper fingers for holding the Interface Tooling from behind by its' mating grip handle. Has THK linear bearings and pneumatic rotary actuator with cam for open/close. Spring-loaded to closed position

Pneumatic robot gripper provides grip motion (8mm stroke per finger)
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

Telescoping arm with permanent portion of AP Absorber EOAT

Interface Tooling

AP Absorber

All 3 put together
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

- Telescoping arm
- Permanent portion of the EOAT
- Interface Tooling
- AP Absorber EOAT
- AP Absorber
1. Starts with AP Absorber Interface Tooling inside the containment box and mounted to the end of the telescoping inner arm. No Target present in HRS
2. Containment box and main arm move 12” forward together – enclosing the vacuum window port. Box is above the cask and still behind the cask front wall.
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

3. Main arm extends approx. 12’-6” using servo drive axis. EOAT now near the Target mounting ears but does not touch.
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

4. Inner arm extends through the Target mounting area another 6’-8” with pneumatic telescoping motion
5. Final 2” forward move w/ servo axis, then EOAT motions release AP Absorber from mount (grip AP Absorber by its’ 3 handles, lift 15mm), then pull back 2” and lower
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

6. Retract inner arm
7. Retract main arm – pulling Interface Tooling and AP Absorber back into containment box. Interface Tooling pilots onto hanger rods inside box.
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

8. Retract main arm and containment box 12”
9. De-couple from Interface Tooling by opening dovetail gripper and retracting arm approx. 20” to full retract position.
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

10. Lower containment box 27” to get top of box below window flange
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

11. Move containment box forward 12” again to line up top of box with cask interior
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

12. Lower containment box into cask (approx. 10”). Open dovetail gripper, releasing containment box
13. Move box gripper up 37” to full vertical retract position
14. Move box gripper back 48” to full horizontal retract position – clearing space above cask. >>> **AP Absorber extraction process complete**
Detailed Review: Design of RH Target Module and how handles the Anti-Proton Absorber

15. Install: no containment box and no cask, new Interface Tooling & new AP Absorber pre-loaded on end of arm. Extend telescoping arm, EOAT motions install AP Absorber
Design Features re: Contamination Control and Error Handling / Recovery

- Tapered section of the endcap center tube to funnel in possible broken/hanging spokes as the arm retracts.

Contamination-containment box

Target Cask

2”

6”

6”

2”

8”
Design Features re: Contamination Control and Error Handling / Recovery

- Minimal holes/gaps in the Interface Tooling main plate closing off back of containment box.
- Containment box top plate closes off lower cask air volume.
- 3/4” typ. gap.
- Window mounting flange.
Problem scenario: Target gets stuck on mounting surface inside HRS
Problem scenario: Target gets stuck on mounting surface inside HRS

Helical cam: 1/16” (.0625”) lift thru 90 deg. rotation of guide-pins in retract position

Provides .050” separation of bicycle wheel from HRS mounting surface
Problem scenario:
Window gets stuck on mounting flange
Design Features re: Contamination Control and Error Handling / Recovery

4X push-off bolts in threaded holes. Can use to push window off of mounting flange using the same robotic bolt-driver that operates on the bolt circle.

2X bullet-nosed hanger rods hold window when bolts are in backed-out position.

Machined-in dovetail grip handle on top of window.

**Problem scenario:** Window gets stuck on mounting flange.
**Problem scenario:** Arm drive axis stops working while arm is extended into bore
Problem scenario: Arm drive axis stops working while arm is extended into bore

Horizontal servo/chain drive axis not designed yet, but will have method to detach from drive chain – thus allowing arm to be pulled back manually w/ long-handled tool from RH room

Same will be true for horizontal motion of containment box
Problem scenario: Horizontal motion of cart stops working while out in the target hall
Problem scenario: Horizontal motion of cart stops working while out in the target hall.

Cannot attach permanent tether since it would block the sliding shield door from closing. But will have a hook for tether to be attached using a long-handled tool from RH room. Cart then can be pulled back.
## Design Features re: Contamination Control and Error Handling / Recovery

### Error Handling / Recovery Summary Table:

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stuck Target</td>
<td>Built-in method to force apart w/ very high mechanical advantage: 3x push-off cam &amp; rollers</td>
</tr>
<tr>
<td>Stuck Window</td>
<td>Built-in method to force apart w/ very high mechanical advantage: 4x push-off screws</td>
</tr>
<tr>
<td>Arm stuck in extend position</td>
<td>Uncouple from drive, pull back manually</td>
</tr>
<tr>
<td>Cart stuck out in target hall</td>
<td>Attach tether, pull back</td>
</tr>
</tbody>
</table>
Prototyping Plans

1. **Prototype of the Target Module EOAT (End of Arm Tooling)**
   a) To include all motions for handling the target, pneumatic powered
   b) No electronic controls (thus will manually sequence the valves)
   c) To include the target bicycle wheel and spring-latches
   d) To include target mounting features from the HRS bore
   e) To also include the AP Absorber, it’s mount, and the EOAT
   f) Design to start this month
   g) Planned to be operational by mid-summer 2016

2. **Prototype of the Window and Window Module bolting / vacuum-sealing process**
   a) To include all servo motors for torque-feedback controlled bolt tightening
   b) To include some electronic controls (part of the process being verified)
   c) To include full sized Window and all spring-loaded / captured bolts
   d) To include a window mounting flange, mounted to a vacuum chamber
   e) To include vacuum instrumentation to verify quality of seal
   f) Design to start beginning of FY2017
   g) Planned to be operational by mid-summer 2017
Next Steps . . .

1. Target EOAT prototype
2. Finish designing the bolting and window-handling portion of the Window Module
3. Window bolting / vacuum sealing process prototype and testing
4. Complete remaining portions of mechanical design for both modules
5. Design pneumatic system, EE to design control hardware and software