**MeV Testing Area (MTA) - Removable Beam Absorber**

**Efren Blas**

**Advisors: Carol J. Johnstone, Robert Ridgway**

*Accelerator Division, Fermilab, Batavia IL 60510*

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**Abstract**

The MeV Test Area (MTA) houses 2 beamlines within the hall: the primary beamline which transports the Fermilab 400-MeV LINAC proton beam into the MTA, and a secondary production beamline that collects pions produced from a 3cm tungsten target sits at the end of the primary beamline. Both lines connect via a steel vacuum housing with the tungsten production target resting inside the housing that produces pions which decay in the secondary line into muons. A longer target or beam absorber downstream of the production target is required to stop the remaining proton beam left over after pion production while also having the ability to be removed from the direct line of the H- ion beam (proton beam) [1]. In addition, an analysis of the current beam absorbers temperature will be performed to analyze the heat conduction and dispersion throughout the system during operation or testing and compare data to the material’s melting point.

1. **MeV Testing Area: Introduction**

The MeV Testing Area (MTA) is one of the various experimental areas within the lab and sits downstream of the LINAC particle accelerator. The primary beamline runs a length of ~21.8’ between its cutoff from the LINAC tunnel towards the target chamber where the tungsten production target sits. From the target chamber, the secondary beamline runs a length of ~25.3’ towards the Muon Detector which sits at the end of this beamline 30.6° from the target chamber. The cutoff of the primary beamline when running through the MTA transitions into the solid stainless-steel tubes that end once it reaches the target chamber via one of the connecting ports. 180° of the primary beamline is a continuation of the another 1’ of stainless-steel tube with an open end that reaches to the roped off contamination zone where the removable beam absorber will be.

1. **Objectives**

Due to the MTA currently having a non-removable beam absorber, there has been a need for a removable beam absorber that can be easily moved and maintain the radiation within the contamination zone and easily measured after each test run with the LINAC proton beam. While the MTA has a beam absorber in use that has been tested during this summer, other beam absorber designs will need to be tested in a simulation. Achieving these results will require an ANSYS Analysis that is specifically looking at the temperature experienced.

1. **Removable Beam Absorber**

**3.1 - Design Phase**

Initial ideas for the removable beam absorber (RBA) were explored during the design stage. Computer Aided Design (CAD) software (Siemens NX) was used to design potential parts/components of the removable beam absorber that would be utilized in the final assembly. A total of 3 design ideas were explored for the potential final assembly.

1. Sliding a pedestal assembly on rails within contamination zone
2. Vertical movement of a mounting plate utilizing large screws that can be twisted
3. Sliding a pedestal assembly on a sliding plate within contamination zone

**3.1.1 - Design Idea: 1**

It was originally intended to use a rail system for the removable beam absorber that could allow the entire assembly to move horizontally but remains within the roped off contamination zone. The rails would either be made from scratch and custom to fit the area but would require modifications of the beam assembly or an entirely new assembly to carry the beam absorber. Another approach to the idea was to use existing “rails” design (square support bars with slots in the center of each face running the length of the bar) due to the slots which can provide the necessary space for wheels to roll in the slots.

**3.1.2 - Design Idea: 2**

Further inspection of the MTA after running the beam to test the beam absorbers capacity to withstand a beam at normal operating capacity fostered the idea of utilizing a method that could vertically move the beam absorber between 3”-5” down from a fixed position (in line of beam). One approach to the idea was to use a system like a vice. A platform connected to 2 threaded rods that are inserted into blocks that hang onto the pedestals explored this concept of manually raising the lowering the beam absorber. Implementing this would eliminate the need to move the entire removable beam absorber assembly.

**3.1.3 - Design Idea: 3**

An idea that takes on a nearly identical approach to the horizontal movement of the RBA from Design Idea: 1, however, the need to redesign the pedestal assembly to fit in rails is eliminated when using a sliding plate. The pedestal assembly can remain intact with the pedestal stands connected to a single sliding plate (14” x 45.0625”) compatible with the 3/8” holes at the bottom allowing for the stand to be inserted and rest on the plate with its 3/8” circular inserts. The inserts will have .1875” threaded holes to screw on a large cap that will completely secure the pedestal assembly. A sliding plate guide ~5’ long by 16.125” wide will consist of backets on both sides across its length to hold down and guide the direction of horizontal motion of the pedestal assembly connected to the sliding pate guide. Both objects will utilize stainless steel but won’t be in direct contact with each other as PTFE multifil [2] material (low coefficient of friction similar to ice) will form a thin layer to complete the slide.

**3.2 – Components**

Of the 3 designs that were proposed, Design Idea: 3 came out as the most favorable design for the MTA. Some reasons for this decision involve the potential to modify and make additions and implement a ready-made design that required minimal custom components to complete the assembly.

Sliding Plate Guide – A large plate with solid hooks or guides on both sides running the length of the plate provides a path for sliding plate to follow with a gap of .125” added to the 14” width the sliding plate has. The guides leave a height gap .625” and follow the same .125” added space to allow for easier movement. The length spans 66” (>5’) to give ample space to move the beam absorber a long enough distance away from the beamline.



Sliding Plate – The dimensions of the plate are 45.0625” x 14” x 0.5” and uses the center circular holes for reference to align the pedestal assembly. Hole extensions .375” in diameter on the top side of the plate are made to align with the pedestal 4 holes, each .375”, and tie down once fully inserted and resting on the plate. With the sliding plate inserted in the sliding plate guide and the pedestal tied down to the sliding plate, the RBA assembly is nearly secure and complete.

Mounting Plate – Used as a reference point for the entire assembly. The plate designed by Robert Ridgway (supervisor) [2], is symmetrical with 3 holes on both sides including slots on the sides of the holes. The center hole is used as the reference point to align the pedestal while the other 2 holes closest to the ends of the plate align with the rods. The mounting plate is secured with the rods and nuts and can be adjusted to a certain height and position. The plate will hold the beam absorber and the casing along with it.



Pedestal Assembly – 2 identical pedestals designed and provided by Robert Ridgway (supervisor) [2] rest on the sliding plate as explained earlier. Each pedestal stands at just 5’ tall for the mounting plate to sit on. The components at the top of the stands use a combination of rods, nuts, and guides plates to adjust the vertical rod attached to a cylinder that is connected on 4 points 360° around with horizontal rods. These rods and maneuver as much as the guide plate will permit, thus, giving the vertical rod versatility in tsking any position within the range of motion the connecting rods have. In addition, the stands contain holes that span evenly between the top and bottom of the plates, each hole can be used for added support braces as seen in the image, or for added other components in the future.



Final Assembly of the RBA

1. **Beam Absorber**

**4.1 - Background**

The beam absorber, in contrast to the production target, is a much larger “target” that sits ahead of the smaller production target in the MTA. Unlike the production target which produces pions within the first 3-4cm that undergo decay in matter of nanoseconds, according to Carol Johnstone [1] from her lectures, the beam absorber is meant to absorb the remaining proton beam that has a lower energy after passing through the production target.

Initial concepts and designs of the beam absorber proposed by Carol Johnstone [1] consisted of a copper insert a 3.5” x 3.5” x 3.5” and 4’ of steel to surround the insert and a second design which only involved the 4’ of steel all on its own.

**4.2 - ANSYS Analysis of Original Absorber(s)**

Although the absorber is much larger in size than the production target, the full intensity of the beam at 1.6 x1013 p 15Hz pulses (steady-state) [4] will heat up the core to high temperatures. Data was collected using ANSYS for both proposed beam absorbers by simulating the steady-state conditions provided visuals for the temperature throughout the entire beam absorber. Some conditions were included in the simulation such as assuming the surrounding environment outside of the beam absorbers would remain constant at 35°C and that the copper insert would have a 25% contact area with the steel block, the remaining 75% would remain as unfilled gaps and voids (air).

**4.2.1- Copper Insert Absorber**

With copper having a melting point of 1000°C, the ANSYS model is preformed to ensure that a steady-state operation over time can be maintained below the melting point of copper. Using a graph to model the data (Figure 1), the test run for 800s experiences an instant rise to ~200°C in the first few seconds of the test and continues increase throughout the duration of the test, however, the rate of increase is lower than what it is over time resulting in a cap of <600°C or lower. Another analysis provides a 3D model (Figure 2) for the steady-state operation for 800s resulting in the copper insert to experience a higher temperature between 600°C and 700°C. The heat throughout the steel block is noticeably dispersed due to the copper’s conductivity while maintaining temperature below 1000°C.



Figure – Cyan curve acts as function of the temperature after each second of the tests duration, y-axis is labeled for the temperature in terms of degrees Celsius (°C) and the x-axis labeled for time expressed in seconds(s).



Figure , Temperature dispersion is occurring throughout the system demonstrating copper’s ability to conduct and easily disperse heat as a result.

**4.2.2 - Steel Block**

In the case of a steel block, the test run lasted for 335s and is illustrated with a graph (Figure 3) and 3D model (Figure 4). In comparison to the copper insert, the steel block immediately experiences temperatures of 500°C the first few seconds in the test and follows a similar trend like the copper insert except it caps off at around 1500°C by the end of the test. With the 3D model the max temperature hits 1501°C inside the core of the absorber, this result depicts a major issue with the steel block as it doesn’t disperse the heat even throughout the block and causes the core to maintain extremely high temperatures where the surrounding block averages temperature from 30°C to 193°C.



Figure , the red curve represents the trend of temperature over the 335s, a similar trend is followed just like the copper insert.



Figure , in comparison to the copper insert, the steel insert/core temperature is extremely high will very little heat dispersion, make note of color coding on the right.

* 1. **– Tungsten Beam Absorber**

Currently the MTA has been utilizing 3 solid 4” x 4” x 4” tungsten block lined up and attached to each other serving as the beam absorber. The choice for having tungsten stems from its heat resistance. Tungsten’s melting point is 3410°C making it one of the highest for any known material. The same steady-state was used for this beam absorber and tested during the month of July 2023.

**4.3.1 - Tungsten Production Target**

Related to the tungsten beam absorber, the production target (designed by Michael Glochowsky, Figure 5) [3] is also fully comprised of tungsten but is much smaller than the beam absorber with dimensions of 1.5cm x 8cm x 9cm. An ANSYS analysis is performed specifically to see if the target will withstand the full LINAC intensity/steady-state.

**4.3.2 - ANSYS Analysis of Production Target**

The analysis was performed with 3 different pulse rates per minute (pulse/min) by Michael Glochowsky [3]: 9 (lowest), 18, and 900 (highest and the max intensity). Furthermore, the minimum and maximum temperatures are considered for each scenario to ensure accurate reading of data (Figure 6). At 9 pulses/min the max and min temperatures only have a 2°C difference and average a very low temperature of 339°C, far away from the melting of tungsten. At 18 pulses/min, there is only a 106°C increase of the average temperature and a 5°C difference between the max and min temperatures indicating very little difference between them. With the full intensity of the LINAC at 900 pulses/min, there is a more noticeable difference between the max and min where the max is just above 2000°C and the min at almost 1500°C. The max temperature at full intensity still sits far from the melting point of tungsten reaching just over half of the melting point. As a result, the data collected can indicate the benefit of continuous use of the tungsten beam absorber for its ability to withstand the heat and have such a high melting point capable to experiencing the full intensity of the LINAC.

 

Figure , the design by Michael Glochowsky that was chosen as the production target for the MTA,



Figure , green data represents the production target in the MTA, yellow data was for a potential production “targets” using slices.

**4.4 - Characteristics for New Proposal**

The materials that comprise the beam absorber will consist of a copper insert, a steel block, and a marble case. The copper insert, or copper core, is a 4” x 4” x 4” block centered inside of the steel block. The steel block will house the copper block with 6” on each side of the block to create the shell that experiences the heat dispersing throughout the system. Finally, a marble casing will surround the entire steel block. The reason for including marble is because it has a low residual activation energy giving it two benefits for the MTA: limits any contact exposure to the absorber and contains large amounts of radiation in the area within the beam absorber.

1. **Conclusion**

The MTA operating under the LINAC has provided a basic for implementing the components that are shaping the experiment. Designing the Removable Beam Absorber explored 3 designs that could serve as the final design for a new assembly, each design was discussed for its ability to effectively change the location of the beam absorber within the contamination zone. In this case, Design idea: 3 served as an optimal and favorable idea due to the versatility of the components involved in the assembly, notably the mounting plate and pedestal stand that is currently used for the secondary beamline in the MTA. In addition, the assembly required few custom parts that aren’t too complex by design such as the sliding plate and sliding plate guide that are both derived from simple geometry (rectangles and circles). Choosing the other designs could require more custom parts to be needed for the final assembly such as Design Idea: 1, needing its own custom rails to be made from scratch in the drafting and machining process or an improvision of existing slotted supports.

As for the beam absorber, ANSYS has been able to simulate the full intensity/steady-state of the LINAC. Data of the original design of the absorber (copper insert and steel block) indicates the potential for a newer design using the same components with different dimensions and an added layer of protection (marble) that could prove to be safer for the MTA and its users but also maintain consistent dispersion of heat throughout the system as demonstrated with the original design. The conductivity of copper has been the advantage of the design over all steel which doesn’t disperse the heat from the core.

**References**

[1] Carol J. Johnstone, Fermi National Accelerator Laboratory, Accelerator Division

[2] Robert Ridgway, Fermi National Accelerator Laboratory, Accelerator Division

**Works Cited**

[3] Glochowsky, Michael. “Low Energy Beams at MTA facility: Targetry - Production and Experiment.” *Fermi National Accelerator*, Batavia IL. 2021.

[4] Lee, Ang. “The Temperature Study for Beam Dump Used in Muon-Cooling.” *Fermi National Accelerator*, Batavia IL. 2003.