Muon Beams: Tungsten Targetry Analysis for MTA and PIP-II

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Abstract

Fermilab currently has a 400 MeV particle accelerator which is used for the irradiation testing area. With increasing demand, from industry and academia, for experiments involving low energy muons, it has become apparent that it would be beneficial to Fermilab to have a muon beam available. Tungsten can readily produce muons when bombarded with H- particles, which are and will be produced by the MTA and PIP-II beamlines. Therefore, a tungsten target can be implemented in these beamlines to produce a muon beam as needed.

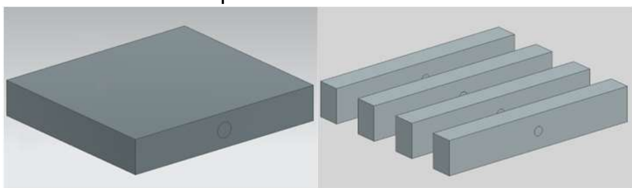


Figure 1, (left) 9 cm x 8 cm x 1.5 cm single target, and (right) four 9 cm x 8 cm x 1.5 cm targets on their sides.

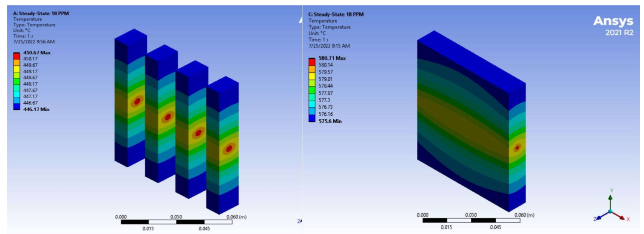
The 400 MeV beam will only produce significant numbers of muons in the first 3-4 cm of tungsten. However, PIP-II's 800 MeV beam will for the first 8 cm. Therefore, to ensure that the tungsten will be compatible with the planned beam design for the MTA, and to have data for a possible future addition to PIP-II, both situations' heat generation will be analyzed via Ansys.

Pulses Per Minute	Average Power Density (MW/m³)	Single Pulse Power Density (GW/m³)	Pulses Per Minute	Average Power Density (MW/m³)	Single Pulse Power Density (GW/m³)
9	34	567	9	13	215
18	68	567	18	26	215
900	340	567	900	129	215

Figure 2, values based on geometry and beam parameters. The blue header signifies a 4 mm diameter, and the green header signifies a 6.5 mm diameter.

400 MeV Beam Assessment

The beam in the MTA is a pulsed beam, so assessments were done for 9, 18, and an extreme 900 pulses per minute. The analyses were done as steady-state average and transient 15 Hz pulses. The analyses were done for different beam diameters as well, as described in the table in Figure 1. The most successful target arrangement was the four-slice series, as illustrated in Figure 2. Since it was most successful, it will be the best option for continuous muon production in the MTA.



Pulses Per Minute	T_{max} (°C)	T_{min} (°C)	T_{avg} (°C)	T_{max} (°C)	T_{min} (°C)	T_{avg} (°C)
9	338	340	339	446	444	446
18	451	446	450	581	576	579
900	2039	1479	1811	2228	1997	2109

Figure 3, images of the different tungsten geometries in an 18 pulse per minute analysis. Table below details temperatures for both target styles in their respective simulations. Green signifies the 4 slice targets, yellow signifies the singular target.

800 MeV Beam Assessment

PIP-II will be a continuous 800 MeV beam, so it will be much more intense. It is so intense that, with all 2 mA of current provided to it, it will melt the tungsten target. Although, PIP-II will be able to take advantage of 8 cm rather than just 3 cm of tungsten for muon production. To take advantage of this, the singular 8 cm target was therefore used for this test. It was found that under continuous firing of PIP-II, the tungsten could withstand 0.02 mA of current safely, reaching 2300 °C. By pulsing the beam at full 2 mA capacity, it was found that 15 ms of beam interception could be withstood under, at most, a 3 Hz 5 ms pulse condition, peaking at 2900 °C.

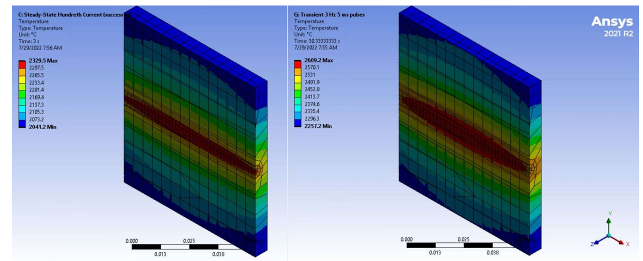


Figure 4, (left) temperature under 0.02 mA of PIP-II beam, (right) temperature under 3 Hz 5 ms pulses of PIP-II under full current. Both are steady-state sectional views through the middle of the production target.

Conclusions

The 4 slice tungsten targets should be used for an optimal muon beam in the MTA, and the single larger rectangular target should be used in PIP-II. For PIP-II, beam intensity must somehow be reduced for the tungsten to be compatible. This could be done by reducing current, pulsing the beam via the chopper, or perhaps by removing some H- particles from the beam via infrared lasers and magnets.

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