STATUS OF PXIE MEBT ABSORBER DEVELOPMENT*

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Abstract

One of the goals of the Project X Injector Experiment (PXIE) [1] at Fermilab is to demonstrate the capability to form an arbitrary bunch pattern from an initially CW 162.5 MHz H- bunch train coming out of an RFQ. The bunch-by-bunch selection will be taking place in the 2.1 MeV Medium Energy Beam Transport (MEBT) by directing the undesired bunches onto an absorber that needs to withstand a beam power of up to 21 kW, focused onto a spot with a ~2 mm rms radius. A ¼ - size prototype of the absorber was manufactured, and its thermal properties are being tested with an electron beam generating a peak power density similar to the one expected during normal operation of the PXIE beam line. The paper describes the absorber concept, the prototype, the testing procedure with the electron beam, and the latest results.

ABSORBER CONCEPT

The PXIE MEBT accepts from RFQ a 2.1MeV, 162.5 MHz CW H- beam with the nominal current of 5mA and forms a desired arbitrary bunch structure with the average (over ~1 μs) beam current of 1 mA by directing undesired bunches to the MEBT beam absorber (Fig. 1). Taking into account a possible future upgrade, the absorber is designed for 10mA.

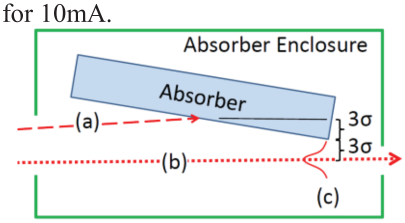

Figure 1: Schematic representation of the absorber showing (a) chopped beam, (b) passed beam, (c) beam profile and 6σ transverse shift between the centers of the chopped and passed beams.

Challenges presented by the absorber design include maintaining vacuum quality, managing surface effects (sputtering and blistering), containing secondary particles, accommodating radiation effects, and the survival of temperatures and temperature-induced mechanical stresses. Following a preliminary analysis [2], the following concept was chosen (Fig. 2):

1. To decrease the surface power density, the absorber surface is inclined so that it occupies all available longitudinal space. It results in the length of ~0.5 m and the nominal incident angle of 29 mrad.
2. To address blistering concerns, the material of the absorber surface is the Molybdenum alloy TZM.
3. The absorber is divided longitudinally into 4 identical units to ease manufacturing and maintenance.
4. The absorbing part of each unit is manufactured from a monolithic TZM piece with slits to relief the longitudinal stress, steps to shadow the slits from beam, and narrow transverse channels for water cooling.

At the absorbed power density of 22 W/mm^2, this design results in predicted absorber surface temperature of ~1000 ºC, well within TZM capabilities.

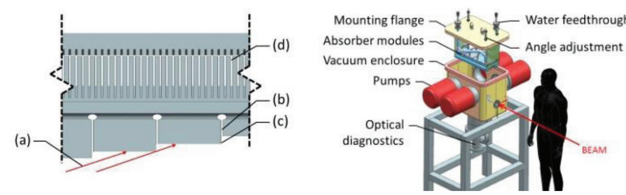

Figure 2: Conceptual design of the MEBT absorber. Left: side view of absorber showing (a) beam incident on surface, (b) stress relief slits, (c) shadowing step increment (magnitude exaggerated), (d) 300μm wide by 1mm pitch water cooling channels. Horizontal scale exaggerated. Right: exploded view.

ABSORBER PROTOTYPE

To assess feasibility of manufacturing an absorber following the concept discussed above, to develop diagnostics and elements of protection system, and to test the simulations against measurements with an electron beam, a ¼-size prototype was manufactured (Fig. 3).

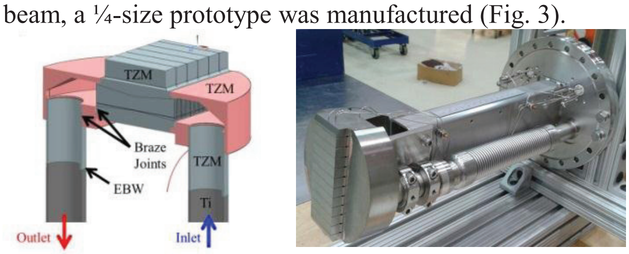

Figure 3: Absorber prototype. Left: cross section of 3D model. Right: Photo the assembled prototype.

The manufacturing process included EDM machining of the TZM parts, EB welding of a Ti tubes, two-stage TZM-to-TZM brazing using Palcusil 25 and 82Au/18Ni, a roll-bonded Ti-to-SS transition, and the final assembly with stainless steel structure and cooling lines. The prototype length along the beam is 116 mm. The “bowtie” channel profile visible in Fig. 3 optimizes the coolant velocity distribution. The stress relief slits have a longitudinal period of 10 mm. The longitudinal heat transfer between parts separated by these slits (“fins”) is low in comparison with the flux from the surface to the underlying water channels. Therefore, a reasonable

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representation of the thermal regime can be achieved even when the electron beam footprint is significantly shorter than that expected for the PXIE absorber. To approach the power density expected at the absorber, the prototype surface has a larger angle with the beam axis, ~150 mrad. The angle can be adjusted by both mechanical position of the prototype and by deflecting the beam. The prototype is equipped with 6 thermocouples located inside its body at depth from 2.4 to 9.2 mm from the surface and penetrating from the top or bottom of the absorbing body.

TEST STAND AND FIRST RESULTS

The thermal properties of the prototype are being tested with an electron beam at a stand using parts from the former Electron Cooler project [3]. A 28 keV, up to 0.2A electron beam is generated in an electron gun, is focused by a solenoid, and either passes through a test chamber into an electrically insulated collector or is directed by dipole correctors to the surface of a tested object (Fig. 4).

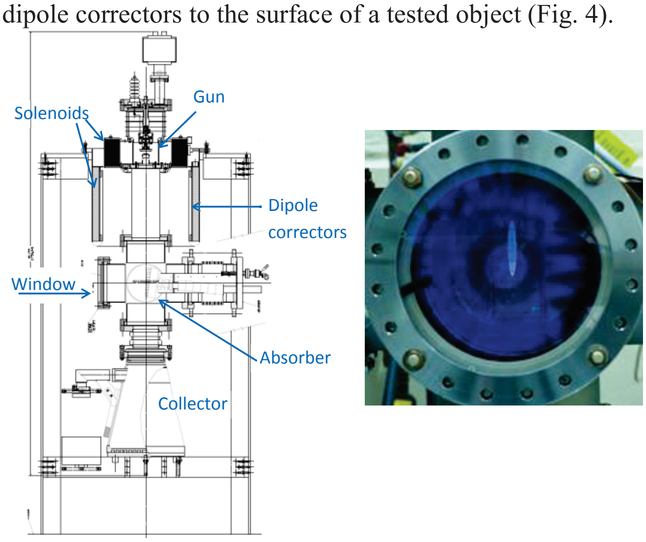

Figure 4: Absorber test stand. Left – schematic. Right – photo of the beam image (M. Murphy).

The beam current is regulated by a potential of an electrode in front of the cathode. The test chamber is a standard 6-way cross with 8” flanges. The prototype is inserted through one of horizontal ports on a long bellow, which allows its removal from the electron beam path. The opposite port is covered by a quartz vacuum window for optical measurements, with an additional lead glass installed on the air side for radiation protection. Another horizontal port is used for vacuum pumping by a 300 l/s turbo pump, and the remaining port houses a movable feedthrough with an electrically isolated test plate for initial beam tuning. The gun is pumped by a 20 l/s ion pump, and the test chamber vacuum is measured by an ion gauge. The vacuum in the gun/test chamber is 0.1/3 nTorr with the cathode off, and ~10/70 nTorr with the 0.2 A beam on the prototype.

Initial commissioning of the stand was made with a simple absorber “pre-prototype”, where a TZM brick was bolted to water-cooled pipe with a thin carbon foil between the matching surfaces. Despite of simplicity, the pre-prototype allowed running the maximum current its surface, so that the required diagnostics, protection software, and measurement procedures were developed.

One of difficulties with the test stand, initially underestimated, is a large amount of energy reflected from the prototype surface, mainly in a form of secondary electrons. On one hand, this effect decreases the amount of the absorbed energy, making the comparison with the H- case more difficult. On the other hand, the secondary particles heat up the test chamber and irradiate the window. A borosilicate viewport that was initially installed darkened (to a brownish color) and eventually cracked. Presently, the stand employs a quartz glass window separated from the absorber surface by an additional spool piece and an air blower removing the heat from the test chamber, so the chamber’s temperature stays below 250C. Judging by bluish glowing of the quartz surface (Fig. 4), the window is still irradiated, but its temperature is low, and we do not see any detrimental effects.

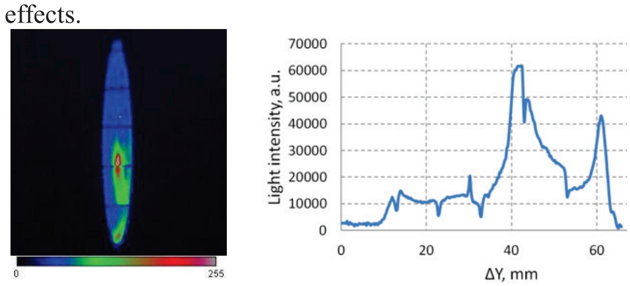

Figure 5: OTR beam image. Left – beam image in false colors; beam current 0.2A, beam ellipse axes are 7.4x52mm. Right – light intensity in vertical midplane.

The power reflection coefficient can be determined by analysing the power removed by cooling water. At fixed absorber and beam center positions, the measured temperature difference between the prototype’s water output and input is linear with the beam current. However, presently a large uncertainty with calibration of the flow meter allows giving only a rough estimate of the reflected energy as between 50% and 70%.

Important information about the beam size and current distribution comes from the Optical Transition Radiation (OTR) beam image on the absorber surface (Fig. 5), continuously monitored by a camera. In a case of a low power density (defocused beam), the amount of the emitted light is proportional to the beam current. If the beam is focused more tightly by the solenoid, the image exhibits a fast nonlinear growth of the light intensity either at the beam center or toward the position of the best focusing (the bottom part of the absorber for the case of an under – focused beam in Fig. 5).

The software allows measuring the light integral as the sum of pixel intensities over a chosen rectangle. Fig. 6 shows the measurement, when the rectangle is set over a single fin and the beam is being focused. With a larger portion of the beam coming to the fin, the temperature of a thermocouple with a depth much smaller than the

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transverse beam size grows linearly with the incident portion of the current, and so does the light integral. Above some temperature, this linear relationship breaks, and the light integral grows exponentially, indicating that thermal photons affect the image. According to thermal simulations of the prototype, the surface temperature at the transition is ~500 C.

Note that there are several millimeter-size spots at the absorber surface which begin thermally radiate at the power density several times lower than the onset of the thermal radiation in the beam center. These "hot spots" may be related to the quality of the surface finish, so that the local angle with the beam is significantly increased. In the tests with the pre- prototype, surface of which was not finely machined, the number of such hot spots was much higher.

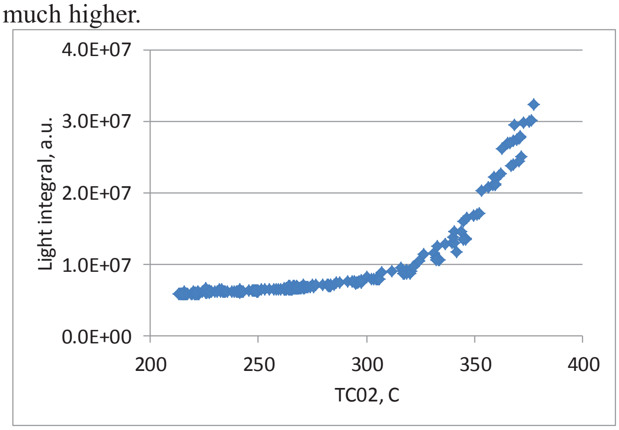

Figure 6: Integral of light recorded from a single fin (#8) as a function of the temperature of the underlying thermocouple. The thermocouple center is located in the middle of the fin, 2.4 mm from the surface. Beam current is 0.19 A. The highest temperature is when the beam footprint ellipse was 6.4x45 mm.

The most important tool for analysing the prototype properties is a set of thermocouples. In part, one of the fins, 5th from the top, is equipped with 4 thermocouples at various depths. Location of the thermocouples was verified by moving a small size, 5mA beam over the prototype surface (Fig. 7).

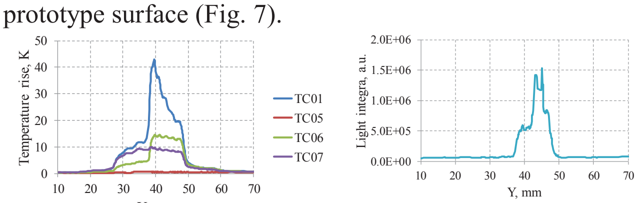

Figure 7: Vertical scan of the fin #5. In horizontal direction, the beam is centered in the middle plane of the prototype. Left: rise of temperatures with respect to the incoming water. Thermocouple depths, in mm, are 2.65, 6.15, 9.15 for TC01, TC06, and TC07, correspondingly; TC05 is below the water channels. TC06 is shifted by 6 mm from the transverse midplane, and others are in the middle. Right: the light integral from a rectangle covering the fin #5. Peak in the center corresponds to thermal radiation.

Behaviour of temperatures is in qualitative agreement with expectations. The increase of the temperatures when the beam is on the upstream fin is explained by the thermal conductance along the thermocouples and is taken into account in further analysis.

The equilibrium temperatures were measured at several beam currents and sizes, and the results were compared with the 3D thermal simulations in ANSYS [4]. The beam footprint was assumed to be an ellipse with a constant power density. Within the (currently large) uncertainties in energy deposition and surface temperature, the FEA model predictions appear to be consistent with measured prototype temperatures.

DISCUSSION AND PLANS

If one uses the scaling from simulations, the maximum surface temperature was so far ~600C at the power density of ~10 W/mm^2. No measurable changes in the prototype performance were observed, but an elliptically-shaped, whitish discoloration has appeared at the surface. While it may be a result of melting of one of the hot spots, we plan to establish an independent verification of the absorbed power and surface temperature before the further increase of the power density and, finally, thermal cycling tests. One of planned measurements is the water power balance with a calibrated flow meter. Another is a measurement of the surface temperature with a pyrometer and/or with a measurement similar to Fig. 5 but involving a narrow band filter.

Preliminary results of testing the prototype look promising, and we are confident that the choice of TZM as the absorbing material is appropriate. On the other hand, because the reflected power is significant in the case of H- beam as well, ~25%, the 21kW requirement for the absorbed power at 10 mA operation can be correspondingly relaxed. That as well as complexity of the present concept, difficulties encountered during manufacturing, and unexpectedly good performance of the pre-prototype encourage considering a simpler design.

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