# THERMO-MECHANICAL DESIGN OF PARTICLE-STOPPING DEVICES AT THE HIGH ENERGY BEAMLINE SECTIONS OF THE IFMIF/EVEDA ACCELERATOR *

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*Abstract*

The IFMIF/EVEDA linear accelerator is a 9 MeV, D+ prototype for the validation of the 40 MeV final IFMIF design. The high intensity, 125 mA CW, high power beam (1.125 MW) produces an extremely high thermal load in all the elements intercepting the ions.

Independently of the final purpose of each device, if its working conditions imply stopping a non-negligible amount of particles, the associated thermal solicitation greatly determines the design constraints.

The present work will summarize a thermo-mechanical design workflow that can be applied to any beam facing element of high current accelerators and its application in beam dump, scrappers and slits design. This approach is based on analysis experiences at the IFMIF/EVEDA project and, while taking into account the particularities of each device, uses the same tools and parameter evaluation criteria for all of them.

## INTRODUCTION

Different scrapers are located in the transport lines indicated in Figure 1, and a beam dump is required to stop the beam exiting the accelerator during commissioning and accelerator tests, so all these elements must operate in pulsed and CW modes.

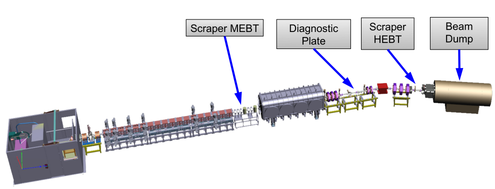


Figure 1: Scheme of the IFMIF/EVEDA accelerator, showing location of particle stopping devices.

## REQUIREMENTS AND BEAM CONSIDERATIONS

Stopping beam particles on a safe and reliable way shall be the most important objective of the design. The working conditions have to be simulated as best as reasonably possible, including normal, off-normal and accident situations.

The basic load that the material has to handle is the heat generation that comes from the ionization of caused by the beam particles. The usual way to describe the beam is model it as a Gaussian distribution. The different acceleration stages of IFMIF/EVEDA prototype produce a beam that is more squared so the information of the particle simulations must be used for the design.

The penetration of the ions depends on their energy and the material properties. For a given power, high intensity accelerators produce a higher volumetric heat generation. Figure 2 shows how the inclination of the beam facing wall allows to reduce the surface thermal flux but not the volumetric load peak. Fortunately, the mean values for both, thermal gradient and stress inside the material depend on the equivalent surface load.

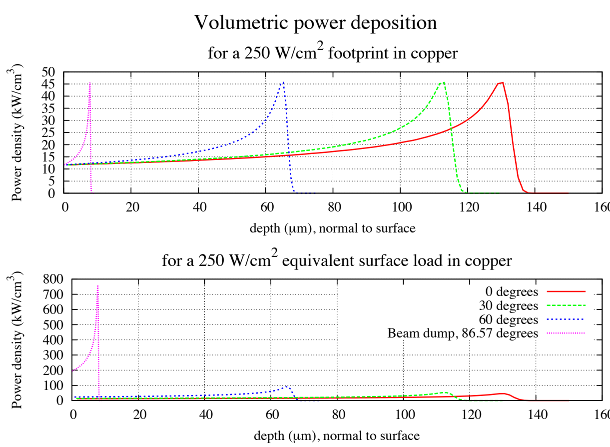


Figure 2: 9 MeV deuterons penetration vs. incident angle.

The worst load case corresponds to a CW beam (full power), where mean and peak values are equivalent. The beam load can be simplified to a surface thermal flux in a conservative and accurate way. The approximation is better as the incident angle is higher and the rate of particle penetration to wall thickness is lower.

## WORKFLOW FOR THERMO-MECHANICAL DESIGN

The devices designed have in common that their main function is to stop ions of a high current CW beam. This fact is so determinant that the process of design of the three of them can be synthesized in a common workflow.

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The inputs for the design are the beam dynamics requirements, functionality and design and fabrication constraints. It is important to note that the design constraints represent an heterogeneous group of inputs, including radioprotection issues, space limitations, interfaces, assembly procedure, maintenance, etc.

Usually, the first preliminary design is a good start point if the inputs are clearly stablished. The power deposition is computed using an in-house code. Cooling needs are a direct result of this deposition, followed by FEM thermal and mechanical analyses, possibly of several kinds. The simulation output is used for the reference code checking procedure. If the error of any analysis is greater than the security factor, model must be refined, studied in detail or different type of simulation has to be performed. In this loop for improving the accuracy, a CFD simulation is generally added to validate the initial cooling dimensioning. If any of the checks is far from be satisfied, the design is modified and the analysis procedure is restarted.

## BEAM DUMP DESIGN

The conceptual design of the beam dump in Figure 3 is based on the LEDA ogive beam stop, after a preliminary comparison to plates and other geometries [1]. The shape is simplified to a cone as one of the design goals is to have a high robustness to beam errors in size, centering and shape represented in Figure 4. The flange of the cone could be design to safely stop the tails of the beam, allowing to handle higher focusing errors.

Results, exemplified in Figure 5 and 6, show a great robustness to beam errors, CW and pulsed mode operation, buckling and high velocity coolant flow effects [2].

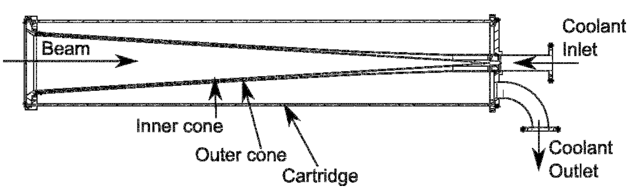


Figure 3: Preliminary design.

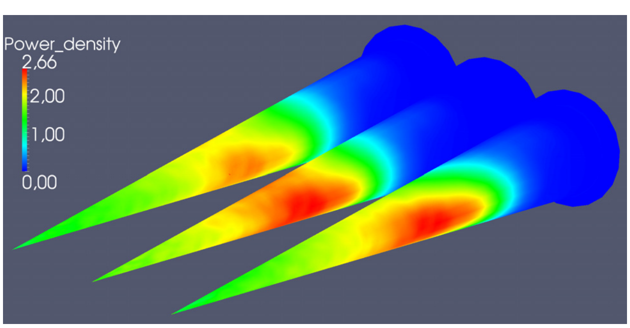


Figure 4: Power deposition (MW/m$^2$) of nominal (left), focused (center) and shifted (right) beams on the inner surface.

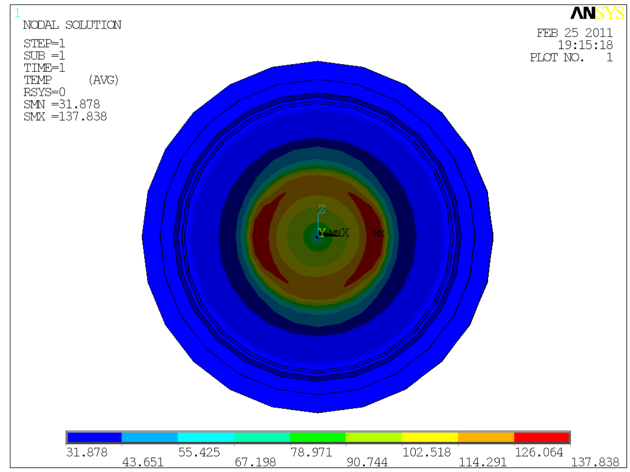


Figure 5: Thermal analysis. Temperatures ($^o$C).

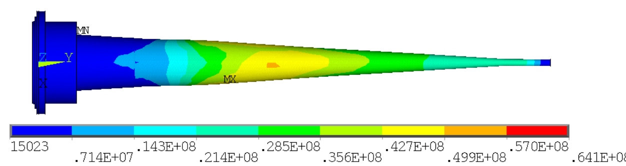


Figure 6: Mechanical analysis. Von Mises stress (Pa).

## MEBT SCRAPER

It is located between RFQ and cryogenic linac cavities with the aim of scrape the particles below 5 MeV. This collimator is mobile and information about the power being scraped has to be available.

Available space has been the most important constraint, having only 80 mm for the whole assembly. The thermal load was a direct input [3], divided in the three different hypothesis of Table 1.

Table 1: Thermal load hypothesis for the MEBT scraper

| Load case | Description | Total power (W) | Max. density (W/cm$^2$) | Area (cm$^2$) |
|---|---|---|---|---|
| **0** | Theoretical nominal | 3 | 1.5 | 2.0 |
| **1** | Real nominal [3] | 30 | 15 | 2.0 |
| **2** | Off normal density | 300 | 150 | 2.0 |
| **3** | Off normal power | 522 | 30 | 17.4 |

The total heat that has to be evacuated is low. This allows to have a small cooling channel section and a low temperatures which discard the need for pressurized water.

Even though the load cases are very conservative, the thermal and mechanical results summarized in Table 2 indicate a high margin to failure. Worst cases are shown in Figure 7 and 8. As it is a security element, at least one Type-K thermocouple will be installed, immersed in the copper, to monitor the thermal load through the copper temperature.



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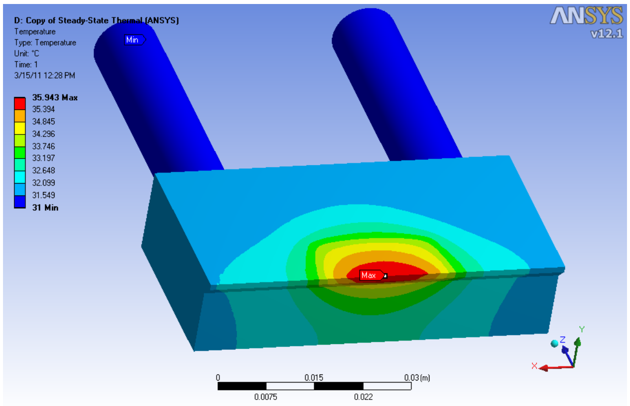


Figure 7: Temperatures for load case 2.

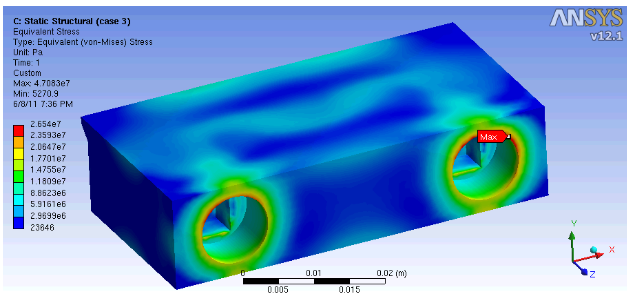


Figure 8: Von Mises stress in copper for load case 3.

## HEBT SCRAPER

This element is needed to protect beam tube, flanges and bellows located in an area where maintenance is not feasible once the beam dump inner cone has been highly activated. As opposed to the MEBT scraper, the device has a fixed position, which allows to give the annular shape in Figure 9. Mechanical security coefficient, Figure 10, is over 2 for the worst load case, which corresponds to a wide opened beam. Temperatures shown in Figure 10 are also kept low enough.

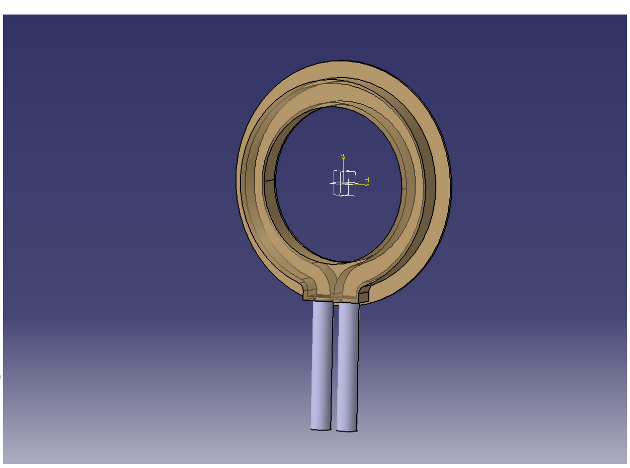

Figure 9: Preliminary design.

Table 2: Results summary for the MEBT scraper

| **Load case** | **Cooper Max. Temperature** ($^o$C) | **Max. Stress** $\mathbf{P_m + Q}$ **in copper** (MPa) | **Stress safety factor** $\frac{3\ S_m}{P_m+Q}$ |
|---|---|---|---|
| **1** | 36.0 | 6.63 | 16.83 |
| **2** | **80.4** | 18.83 | 5.93 |
| **3** | 61.4 | **28.03** | **3.98** |

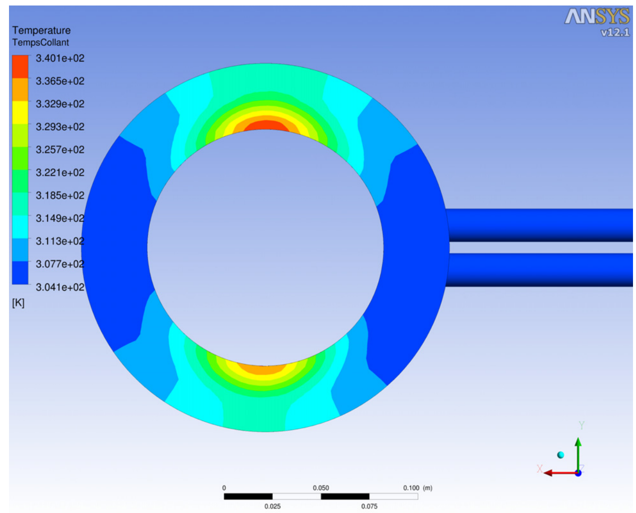


Figure 10: Temperatures for worst case.

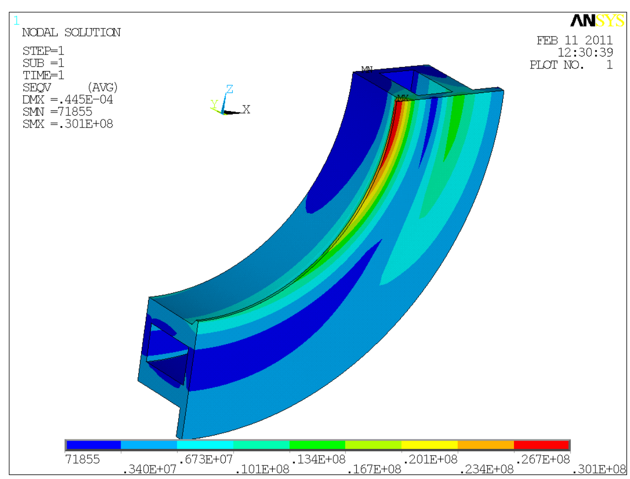


Figure 11: Von Mises stress (Pa) using a double symmetry model.

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[1] B. Brañas et al., “Design of a beam dump for the IFMIF-EVEDA accelerator”, Fusion Eng. Des. 2-6 (2009) 84.

[2] D. Iglesias et al., “The IFMIF-EVEDA accelerator beam dump design”, J. Nucl. Mater. (2011) In press, corrected proof.

[3] N. Chauvin and P. Nghiem, “Scrapers studies for the MEBT” IFMIF/EVEDA Beam Dynamics Group (2010) addendum 4.

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