Studies of target materials and layout for a low emittance muon source (LEMMA)

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The project of a future multi-TeV muon collider needs new proposals to tackle the problems of muon production, accumulation and acceleration, and finally energy dissipation and target maintenance. In the Low EMittance Muon Accelerator (LEMMA) [1] concept the positron beam, stored in a ring with high energy acceptance and low emittance, is extracted and driven to a multi-target system, to produce muon pairs at threshold. This solution alleviates the issues related to the power deposited and the integrated Peak Energy Deposition Density (PEDD) on the targets. In particular, both temperature rise and thermal shock are related to the beam size on target, and power deposition of about 30 kW is expected for a $0.3X_0$ target. Be and C composites/structures are in use and under study for low Z target and collimators in accelerators for high energy physics also because of the stringent vacuum requirements in such complexes that are not easy to fulfil with liquid targets. Recently developed C based materials with excellent thermo-mechanical properties are under study for the LHC upgrade collimators. A 7.5 μs long beam pulse made of 288 bunches with 1.2×10^{11} protons per bunch, which is the full LHC injection batch extracted from SPS, has been used to test both C-based and Be-based targets with maximum temperatures reaching 1000 °C.

A theoretical model to deal with such a scheme has been developed, and the simulations tools have been put in place. The thermal stability and thermal stress induced in solid targets when crossed by focused pulsed beams of positrons has been evaluated in a three steps model. First the energy deposition maps in the target is evaluated. Then, from the induced heat source, the space-time temperature field is numerically calculated. As a third step, knowing the temperature gradients the thermal stress field on the target is also obtained. Christensen or Von Mises criteria [2] are eventually applied to estimate the material fracture risks and safety parameters.

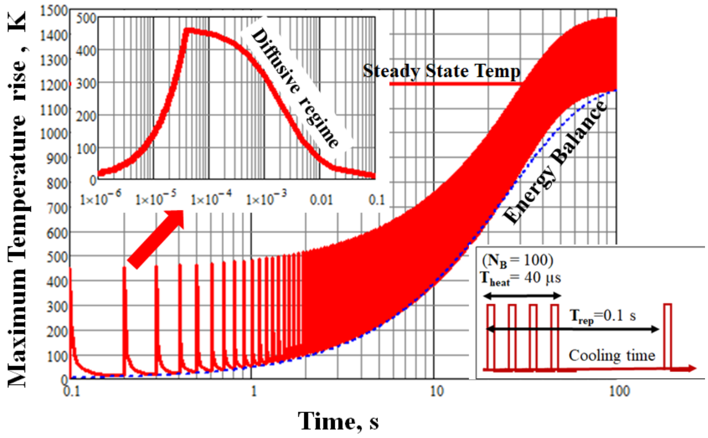

Figure 1: time evolution of the maximum temperature rise for a Beryllium cylindrical target 3 mm thick and with a radius of 5 mm. The target is heated by a train of 100 positron bunches with a Gaussian spot size of 0.3 mm

The study has been performed on Beryllium and Graphite solid targets (respectively 3 mm and 1 mm thick disks), but can be extended to other solid and liquid targets (Li etc..), as well as other kinds of beam particles (protons, photons, etc..). As an example, Fig. 1 shows the temperature rise as evaluated by our model for a Be cylindrical target heated by a train of 100 positron bunches in 40 μs ($3\cdot10^{11}$ positrons per bunch) with a repetition rate of 10Hz (see Fig.1). After 100 s the disk reaches a steady state temperature of 1200 °C as can be calculated by the energy balance between the energy deposited by the positron pulses and the heat loss by radiation (blue dotted line; the target has here a 5 mm radius).

Such a study allowed to develop a rigorous theoretical approach to evaluate the thermal stability and thermal stress of solid targets for example in a low emittance muon source. The developed software calculates both temperature and stress fields, and represents a useful tool for the optimization of both target structure and sequence of the particle beams. The model can be successfully applied to other target materials and layout, as for example the MAP muon source developed in US in the past years [3].

Future R&D: experimental activity

A list of several experimental activities should be planned in the future for an accurate determination of the thermo-mechanical properties of the targets. This is a fundamental task because the real effective properties may differ from the reference literature values used in the numerical simulations.

1. Measurement of the thermo-elastic properties of Graphite disks in a wide temperature range.

2. Measurement of thermal diffusivity and infrared emissivity via photo-thermal radiometry and infrared thermography. A training activity will be carried out to use the infrared camera in passive regime for emissivity measurements and surface temperature estimation, and in active regime with a lock-in system for the determination of internal fractures.

3. Detection of possible damage and thermomechanical stress when the target is subjected to intense laser beams. In fact, the thermomechanical performance of the target can be easily tested with photons bunches, instead of positron bunches, so to perform the measurements with an easier optical setup. The intensity and pulse duration of the optical source should be chosen so to generate analogous space-temporal temperature variations.

4. Thermal relaxation test on 2 or more solid targets with different geometric arrangements. The approach here is to use multiple targets to decrease the PEDD on a single target. A critical point is here the mutual position among the targets so to optimize the infrared radiation mechanism as happens for "*smart radiators*".

5. Ex ante and ex post measurements of the induced surface damage of targets subjected to intense laser beams with profilometry and other standard techniques (before and after the illumination)

6. Ex ante and ex post measurements by XRD of lattice constant changes due to thermoelastic stresses.

7. New setup for temperature measurements: a fast optical NIR sensor can be used for accurate measurement of high temperatures with high spatial and temporal resolution. A feasibility study should be initially performed.

Future R&D: theoretical activity

1. Numerical simulations for the evaluation of thermomechanical stresses on various muon collider architectures. The study can be extended to several targets (solids, liquids), several geometries, and eventually to other kind of particles.

2. Theoretical-experimental fit for the determination of the thermal and elastic parameters of the targets. This activity should be performed together with the experimental activity for the nondestructive testing of materials.

This work will be pursued within the newly formed International Muon Collider collaboration.

References

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