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STUDIES INTO BEAM LOSS PATTERNS AT EUROPEAN SPALLATION SOURCE

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Abstract

The linear accelerator of European Spallation Source will produce 5 MW proton beam. Beam of this power will likely generate significant losses along the beamline. To study these losses, a coherent model of the whole machine is being made using custom generator. This model is used to perform Monte Carlo simulations of the propagation of the accelerated beam and the losses in the MARS code system. Preliminary simulations utilizing the uniform beam loss distribution were done. More detailed simulations based on the various different loss patterns focused around hot spots in magnets were also performed and their results compared. This confirmed the limit of 0.5 W/m average heat load on accelerating cavities foreseen by the cooling requirements. Additional studies investigated the dose absorbed by fragile cooling system's elements during the normal operation of the facility defining their radiation resistance to the levels of few kGy/y. Further simulations will also give the information about the expected beam loss detectors signal at possible locations. These data will be further analysed using custom algorithms.

BEAM LOSS MONITORING AT ESS

European Spallation Source will produce neutrons by irradiating the tungsten target using 5 MW proton beam (H+) at 2 GeV delivered by linear accelerator of around 600 m length [1]. Beam losses along the linac anticipated by the design of the facility are limited by 1 W/m which should allow the hands-on maintenance [2,3]. To ensure that this limit is not exceeded during the normal operation of the machine and also to detect catastrophic events a beam loss monitoring system will be introduced. Additionally, the system will be also used to tune-up the machine by pointing the exact beam loss locations and providing feedback about the beam physics.

The main detector chosen for the linac is CERN LHC type ionisation chamber complimented by neutron detectors and scintillator-based fast loss monitors. The BLM system is designed to detect the losses as small as 1% of the limit (about 0.01 W/m) and as fast as 2 μs (to prevent destruction of elements during full beam loss) [1].

To design and test this kind of a beam loss monitoring system it was desired to create a model of the facility to be used in various Monte Carlo simulations of the beam loss.

MONTE CARLO BEAM LOSS SIMULATIONS

Creating an Accelerator Model

Creating a complete and coherent model of the whole accelerator is crucial for many aspects of the design phase of the machine and can also benefit the users later during the operation phase. Monte Carlo particle transport codes demand huge amount of time spent on creating the geometrical description of the accelerator's components. It is therefore important to coordinate the work and ensure that all created models are coherent with each other and, when put together, represent accurately the machine. This can keep the time consumed by modelling to minimum and prevent doubling of work by avoiding the need of rewriting the code.

CAD to MARS

The tool selected finally for the task of linac modelling at ESS Beam Instrumentation Group is MARS Code System developed at Fermi National Accelerator Laboratory [4]. There were few reasons supporting this decision on top of the fact that MARS was proven to be a reliable code producing results similar to other renowned codes like FLUKA (e.g., [5,6]). Amongst those reasons was the feature of overlapping and overwriting regions in the geometry which allows easier automation of the model generating process. Most of work done up to date involved translation of the CAD drawings of the machine's components provided by the ESS Design Group into a code readable by MARS geometry compiler. The components treated in this way are grouped as modular blocks to be put in various places of the machine multiple times using the automated generator (see about DEIMOS generator later in this paper).

Beam Loss Patterns

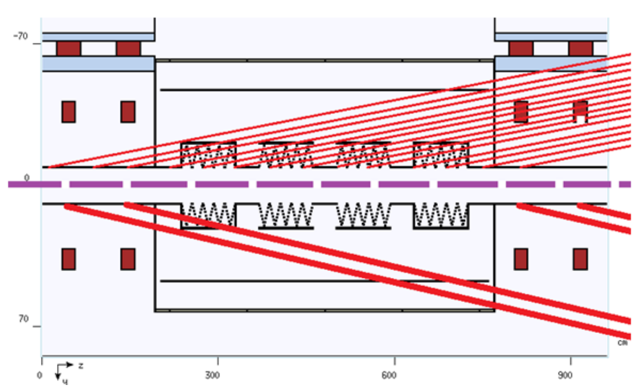

Figure 1: Scheme comparing two loss patterns: uniform (top) and localised (bottom).

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Due to the lack of detailed loss patterns for the ESS linac provided by the beam physics group, assumptions were necessary. The level of proton beam loss was set at 1W/m (as mentioned earlier). Two different patterns were subject of investigation (Figure 1): a.) uniform losses along the whole model b.) losses localized in the quadrupoles (most probable loss points in the actual machine as the region where the beam is the largest) [1]. In both cases the losses propagate at a shallow angle of 0.05 degree in reference to the beam direction and very close to the beam pipe. As more information about beam loss patterns becomes available the loss sources for simulations will be updated.

DEIMOS GENERATOR [7]

All components of ESS linac are listed in the central Beam Line Elements Database (BLED), a system for central management of the data [1]. To ensure that the models used for the Monte Carlo simulations are consistent with the actual machine, a link between them and BLED have been established.

DEIMOS, an ESS Beam Line Generator for MARS is a program written in Python (running on Windows, Mac OS and Linux-based systems for users convenience). As input file it reads the elements names and coordinates from BLED, processes them and outputs a complete accelerator model part readable and processable by MARS (main input window in Figure 2 below).

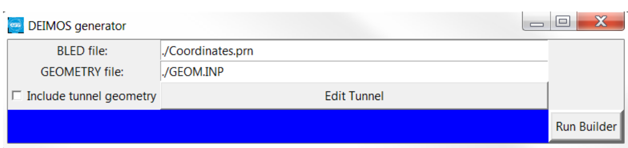

Figure 2: DEIMOS generator main window.

MARS output file includes the accelerator tunnel (predefined as 600x350 cm tunnel filled with air surrounded by concrete walls of thickness 50 cm with ceiling and floor of 80 cm) with all the parts recognised (just by the name thanks to BLED coherent naming convention) in the BLED input. As every part is saved as separate module it is very easy to add new parts or edit existing ones, as well as update the layout based on the changes in BLED. The generator includes all parts whose models are present in its elements library and skips others – that allows to start generating the model with only basic parts like quadrupoles, beampipe and cryomodules with the possibility of including other parts like valves, waveguides etc. later on.

While using a constantly updated library of reproducible accelerator components it is possible, thanks to the DEIMOS generator, to create an up-to-date model to be used in MARS Monte Carlo simulations instantly after introducing updates in parts or accelerator design without the need of manual adjusting. Also having a united library of parts with common material list ensures the coherence of the accelerator modelling and allows the parallel work.

RESEARCH PERFORMED USING ACCELERATOR MODEL

All steps of linac modelling lead eventually to using the model in simulations of the described beam losses to answer particular questions concerning the radiation transport in the machine. Results of these exemplary simulations are presented in this section (few others were presented in [8], e.g. predicted power deposition levels). All simulations were performed to ensure the numerical error of the results below 5% and this error is not introduced in the plots.

Heat Loads in Superconductive Cavities [9]

First task of the simulations was to inspect the foreseen heat load levels in the superconducting cavities of ESS linac, both elliptical and spoke. Results were expected to cover the energy range from 90MeV to 220MeV (spokes) and from 220MeV to 2GeV (ellipticals). Estimating the heat loads was necessary to confirm or update the preliminary cooling requirements, previously established at 0.5 W/m averaged along all cavities.

To ensure maximum safety and a good margin of error all simulations and data analysis were made conservatively. In terms of the simulation setup it means not only performing the simulations for the most probable scenario (losses localised in quadrupoles), but also considering the case much worse from the heat loads point of view (which is having uniformed losses, even in the cryomodules), as explained earlier. Results of the simulations are as follows (Figure 3, Figure 4):

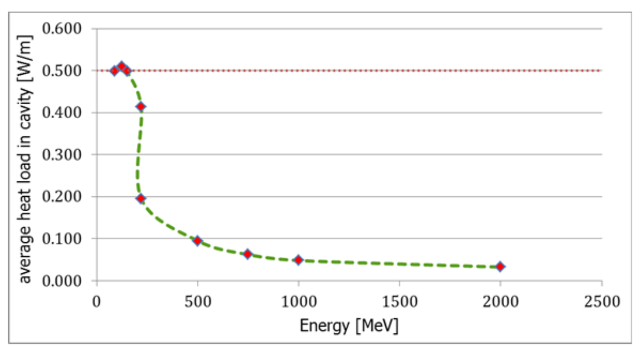

Figure 3: Heat load predictions for the losses in quadrupoles.

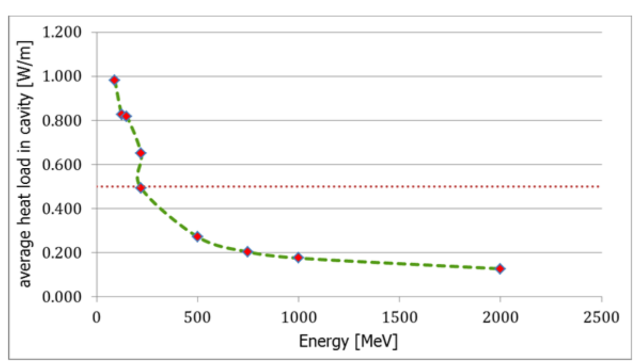

Figure 4: Heat load predictions for the uniformly distributed losses.

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One can observe that the heat load on cavity for lower energies gets closer to the total beam loss (1W/m) – this is due to some other conservative assumptions like normalisation of the heat load per whole cavity to the maximum heat load absorbed observed in it. Nevertheless, even with this overshoot one can state that the average heat load along the whole accelerator will be lower than expected 0.5 W/m (from the point of view of the cooling system this value is more important than the local excess of the limit).

Dose Absorbed by Fragile Cryogenic Components

As part of cryodistribution system is localised very close to the beam, studies for the desired radiation hardness of the more fragile components were necessary. Simulations were performed to investigate on the doses absorbed by Teflon cryovalve localised around 70 cm away from the beam pipe next to quadrupoles.

Only one beam loss pattern was taken into account (losses at quadrupoles, as a more conservative case for this element) and two scenarios – with the element exposed directly to the secondary radiation and shielded by thin layer of stainless steel imitating its cover. The results are presented in Table 1 below.

Table 1: Annual Dose Absorbed by Teflon Element located 70 cm from the Beam Centre Next to Quadrupoles

Teflon @70 cm		**Dose Absorbed [Gy/y]**	
En [MeV]	**cavity type**	**No Shield**	**Shield**
90	spoke	40	30
125	spoke	90	70
220	spoke	380	280
220	ellip	860	500
500	ellip	2000	1300
1000	ellip	1600	1000
2000	ellip	2500	1000

FURTHER WORK

More elements will be added to the DEIMOS library to eventually cover all parts listed in BLED with a rational level of details. Already existing parts will be updated as new CAD drawings become available.

The model will be used to optimize the numbers and positioning of the beam loss monitors. The results of the beam loss simulations (hypothetical responses of the detectors) will be stored in a newly created database together with all of the initial conditions (location of the detectors, type and place of the loss etc.) in order to be processed later [8].

The influence of the x-rays generated by the superconducting cavities on the detectors response and tunnel background will be investigated.

Beam losses in the low energy end of the machine will be specially emphasized as particularly hard to detect and localize.

Additional tasks similar to ones described in this paper ordered by other groups will be also performed using DEIMOS generated model.

CONCLUSION

Having automated model generator linked to the official beam line elements database improves greatly the efficiency of Monte Carlo simulations on various issues connected with the beam losses. Simulations performed so far confirmed the requirements for the cooling system effectiveness and established numbers for the radiation hardness of the elements to be put close to the beampipe.

ACKNOWLEDGMENT

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