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ENERGY DEPOSITION AND DPA IN THE SUPERCONDUCTING LINKS FOR THE HILUMI LHC PROJECT AT THE LHC INTERACTION POINTS*

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Abstract

In the framework of the upgrade of the LHC machine, the powering of the LHC magnets foresees the removal of the power converters and distribution feedboxes from the tunnel and its location at the surface[1]. The Magnesium Diboride (MgB_2) connecting lines in the tunnel will be exposed to the debris from 7+7 TeV p-p interaction. The Superconducting (SC) Links will arrive from the surface to the tunnel near the separation dipole, at about 80 m from the Interaction Point at IP1 and IP5. The Connection Box (where the cables of the SC Links are connected to the NbTi bus bar) will be close to the beam pipe.

The debris and its effect on the MgB_2 SC links in the connection box (energy deposition and displacement per atom) are presented. The effect of thermal neutrons on the Boron consumption and the contribution of the lithium nucleus and the alpha particle on the DPA are evaluated. The results are normalized to an integrated luminosity of 3000 fb^{-1}, value that represents the LHC High Luminosity lifetime. The dose delivered to the SC Links is found to be below the damage limit. Further studies are necessary to correlate the induced displacement per atom to the superconducting properties.

INTRODUCTION

In the framework of the High Luminosity LHC project MgB_2 superconducting links delivering up to 150 kA to the magnets are being developed at CERN[1]. The links will be exposed to the radiation field of the cascades generated by the debris from the Interaction Point (IP).

The dose and DPA in the Superconducting Links (SCL) closer to the beam pipe are evaluated using a Monte Carlo code. The consumption of ^{10}B by the neutron capture reactions is considered.

THE HILUMI LHC PROJECT AND THE COLD POWERING TASK

The Large Hadron Collider (LHC) will remain the most powerful accelerator in the world for at least the next two decades. Its full exploitation is the highest priority of the European Strategy for particle physics.

To extend its discovery potential, LHC will undergo a major upgrade in the 2020s. The objective is to increase its peak luminosity (and thus collision rate) by a factor five beyond its design value and the integrated luminosity by a factor ten. The novel machine configuration, the High Luminosity LHC, will rely on a number of key innovative technologies representing exceptional technological challenges. These include among others: cutting-edge 11-12 tesla superconducting magnets; very compact with ultra-precise phase control superconducting cavities for beam rotation; new technology for beam collimation; and long high-current superconducting lines (hereafter called "links").

In the present LHC configuration, the electrical feeding of the about 1700 LHC superconducting (SC) circuits requires the transfer of more than 3 MA of current from the power converters to the magnets. Now this is done via conventional copper cables for the room temperature path between power converters and current leads, High Temperature Superconductors (HTS) or resistive currents leads for the transfer to the 4.5 K liquid helium bath.

Nb-Ti bus-bars operated in liquid helium at 4.5 K or in superfluid helium at 1.9 K provide the connection to the SC magnets. In the present LHC configuration, power converters and current leads are both located in underground areas, the first mainly in alcoves, adjacent to the machine tunnel, and the second in dedicated cryostats that are near the LHC interaction points and in line with the SC magnets.

All equipment in the tunnel is exposed to significant levels of radiation. In Fig. 1 the dose in the tunnel, normalized at 3000 fb^{-1} is shown. It is a horizontal projection and the Connection Module (CM) is behind the beam line. The CM red colour is just to evidence it and it is not related with the dose, whose level is about the same as in D1.

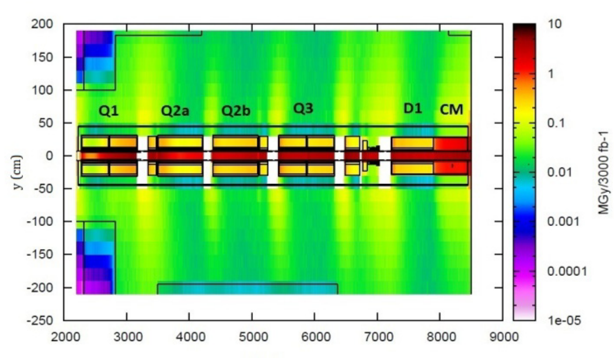

Figure 1: Dose in the insertion region of the tunnel (see text for detail) . The SCL and CM will be at about z=80 m from the IP.

For HL-LHC, the transmission of the current to the magnets is performed via SC links containing tens of cables feeding different circuits and transferring all

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together up to about 150 kA. The cable is shown in Fig. 2. The white part is the cooling He gas.

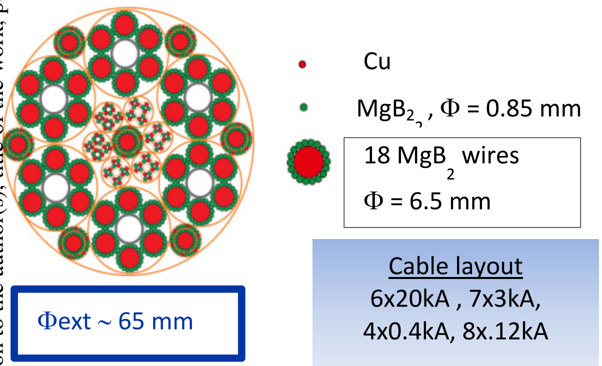

Figure 2: Section of the SCL[1].

SC LINK CONFIGURATION AT P1

The link arrives from surface after the separation dipole (D1, see Fig.1) at about z=80 m from the IP, then goes inside the Connection Module where all the cables of the SCL are connected to the NbTi bus of the magnets. Fig. 3 shows a section of the LHC tunnel with the SCL and the CM. In the model we considered only 1m length of the horizontal (SCL-H) and vertical (SCL-V) parts of the link, the remaining vertical length is further away from the beam pipe with no energy.

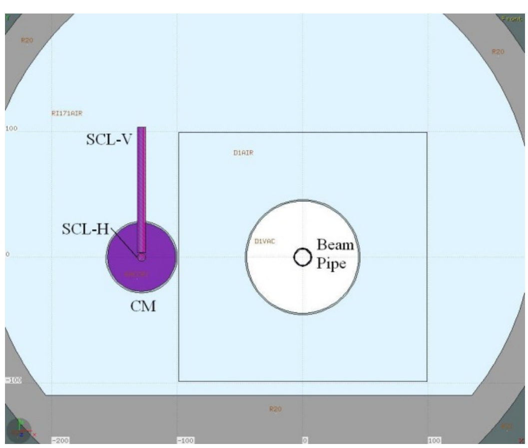

Figure 3: Tunnel section with the SCL.

FLUKA SIMULATIONS

The dose and DPA in the SCL are evaluated using the FLUKA Monte Carlo code[2,3]. The particles entering the SCL are mostly photons and neutrons being on average about 125 photons per 7+7 TeV p-p event and 3.2 neutrons per event. The photons carry on average about 295 MeV per event, so the average kinetic energy per photon is about 2.3 MeV. The neutron contribution is on average about 51.6 MeV per event, with an average kinetic energy per neutron of 16.1 MeV; about 2.2% of the neutrons are thermal and 9.4% have energy below 1 eV. The neutron energy spectrum spans up to 1GeV.

The fluencies of the photons and of the neutrons in the SCL-H are shown in Fig.4 and Fig. 5 respectively.

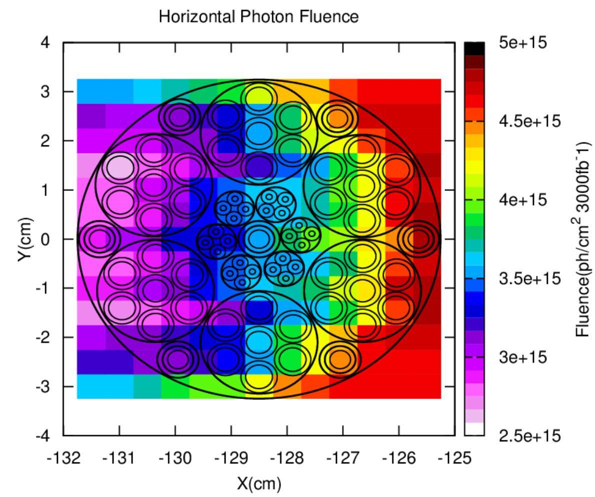

Figure 4: Photon fluencies in the SCl-H.

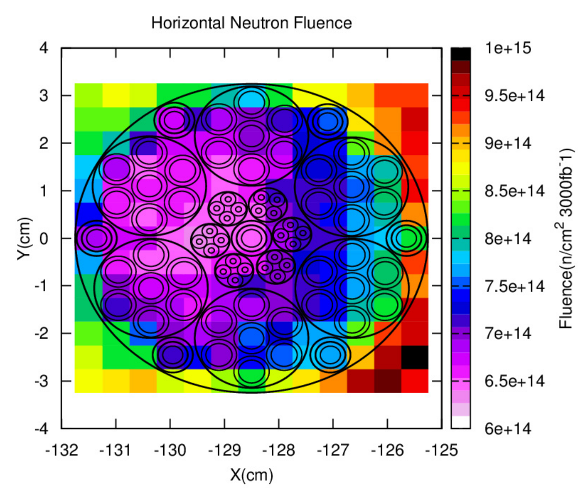

Figure 5: Neutron fluencies in the SCL-H.

The detailed geometry of the tunnel, of the LHC structure and of the SCL are fully defined in FLUKA geometry. The last configuration of the beam screen has been adopted. The material composing the SCL have been accurately defined, according to the cable structure, the natural Boron isotopic composition (20% of ^{10}B, and 80% of ^{11}B) has been used.

The simulations have been obtained with a statistics of 33000 events and all normalized to 3000 fb^{-1}. The cut-off setting were 1 keV for hadrons, 1 MeV for electron and positrons, 0.1 MeV for photons; slow neutrons are taken into account down to thermal energies.

In Fig. 6 the dose in the vertical part of the SCL is shown with a cylindrical binning, with bin dimensions of 0.65 cm x 0.35 rad.

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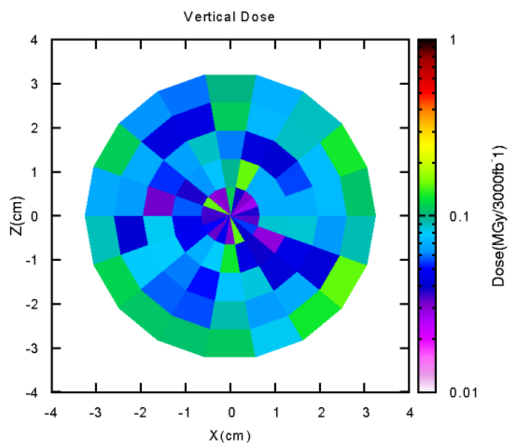

Figure 6: Dose in the vertical part of SCL. The plots represent the average over the whole length of the SCL.

In Fig. 7 the DPA in the vertical part of the SCL is shown.

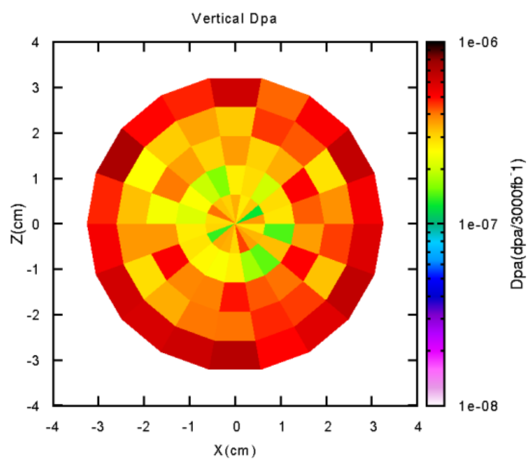

Figure 7: DPA in the vertical part of SCL. The plots represent the average over the whole length of the SCL.

In Fig. 8 the DPA for the SCL-H is shown, the detailed cable geometry is evidenced.

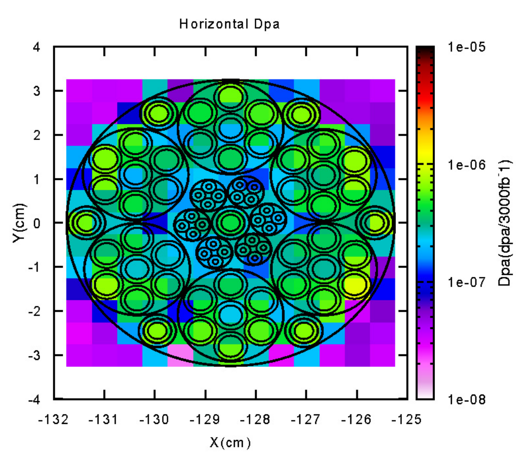

Figure 8: DPA in the Horizontal part of SCL (averaged over the whole length of the SCL). The detailed cable geometry is shown.

As we can see the maximum dose in the SCL is about 0.1 MGy and the maximum DPA is about 10^{-6}. The highest neutron cross section is the one for the capture of thermal neutron by Boron. This interaction produces an alpha particle and a Li nucleus that will depose their energy inside the MgB_2. By considering only this reaction the DPA in the material is about 34% caused by the alpha particles and the remaining 66% by Li[4].

ANALYSIS

The obtained dose and DPA of 0.1 MGy and 10^{-6} respectively should not endanger the functioning of the SCL during the whole machine life.

As a matter of fact if we consider a dose limit of 35 MGy, value at which the kapton insulation starts to lose its insulating properties [5,6], we are well below this limit.

As from irradiation tests [7], values of DPA of 10^{-2} in MgB_2 cause a decrease of the critical temperature from 38.3 to 36 K and an enhancement of the upper critical field. Values from literature indicate that the induced DPA increases the pinning effect [8] at the advantage of an increased performance.

P5 has not been simulated so far, but energy deposition and DPA should not be much different from P1.

The high cross section of ^{10}B (about 20% of the natural Boron composition) for the neutron capture reaction is not a concern for the SCL during the lifetime of the machine, because the amount of thermal neutrons escaping from the beam line and entering the SCL cannot cause a significant damage respect to the whole Boron content.

CONCLUSIONS

A realistic SCL configuration has been used for the simulations. The modelling is based on conservative hypothesis, i.e. without taking into account the external insulation and cryogenic shielding.

The dose and DPA induced into the SCL are well below critical values.

In the next months a detailed layout of the MgB_2 SCL routing will be frozen, definitive simulations with the new layout (longer insertion quadrupoles) will be done.

Since we do not expect big variations in the results of the future simulations, we can conclude that the energy/dose deposition and the DPA in the MgB_2 cables, with the conservative hypothesis adopted, are not a concern over the whole lifetime of the SC links in the LHC machine.

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