SYNCHROTRON RADIATION IN THE INTERACTION REGION FOR A RING-RING AND LINAC-RING LHeC

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Abstract

The Large Hadron electron Collider (LHeC) aims at bringing hadron-lepton collisions to CERN with centre of mass energies in the TeV scale. The LHeC will utilise the existing LHC storage ring with the addition of a 60 GeV electron accelerator. The electron beam will be stored and accelerated in either a storage ring in the LHC tunnel (Ring-Ring) or a linac tangent to the LHC tunnel (Linac-Ring). Synchrotron Radiation (SR) in the Interaction Region (IR) of this machine requires an iterative design process in which luminosity is optimised while the SR is minimised. This process also requires attention to be given to the detector as the beam pipe must be designed such that disturbing effects, such as out-gassing and background scattering, are minimised while the tracker remains close to the IP thus maximising the acceptance of the experiment. The machinery of GEANT4 has been used to simulate the SR load in the IR and also to design absorbers/masks to shield SR from backscattering into the detector or propagating with the electron beam. The outcome of these simulations, as well as cross checks, are described in the accompanying paper which characterises the current status of the IR design for both the Ring-Ring and Linac-Ring options of the LHeC in terms of SR.

INTRODUCTION

The interaction region of the LHeC collider [1] is a challenging radiation environment for both the ring-ring and the linac-ring designs. In both cases, high energy electron beams are bent and focused, resulting in the emission of synchrotron radiation close to the detector and final machine elements. Calculation of this SR, and subsequent control in the design of the interaction regions, is therefore very important for the LHeC. The layout of the IRs is discussed in [2] for the ring-ring design and in [3] for the linac-ring design.

The SR in the interaction region has been computed in three ways. The SR was simulated in detail using a program constructed with the Geant4 (G4) [4] toolkit. In addition the total radiation power and average critical energy was computed in IRSYN, a beam transport and synchrotron radiation Monte Carlo simulation package [5]. A final cross check has been made for the radiated power per element using an analytic method [6].

The G4 program uses Monte Carlo methods to create gaussian spatial and angular distributions for the electron beam, which is then guided through vacuum volumes that contain the magnetic fields for the separator dipoles and electron final focusing quadrupoles. The SR is generated in these volumes using the appropriate G4 process classes.

THE RING-RING DESIGN

For the Ring-Ring (RR) design there are two IR layouts, each defined by the amount of forward acceptance in the detector. The High Luminosity (HL) option has a detector angular acceptance of 10°, whilst the High Acceptance (HA) option has an angular acceptance of 1°. The parameters that are the same for both schemes are the $e^{\pm}$ energy of 60 GeV, the current of 100 mA, and the crossing angle of 1 mrad. The parameters that differ are listed in Table 1.

Characteristic	High Luminosity	High Acceptance
Dipole Field [T]	0.0296	0.0493
Separation [mm]	55	55.16

Table 1: Parameters of the RR design of the LHeC.

We will now study the synchrotron radiation in the IR of each variant of the RR design.

High Luminosity

The HL option contains the lowest amount of SR power creation in the IR, for a total of 33.2 kW.

The SR power and average critical energy for each element are shown in Table 2, computed with the G4 model.

The comparison of the G4 model with the IRSYN MC program and the analytic method are given in Table 3.

The table shows the agreement between the three methods for the total SR power and the average critical energy.

The distribution of the power at the surface of the radiation absorber is given in Figure 1. The red surfaces resemble the absorber and gaps represent bores for the beams. For the HL case SR leaks into the proton bore on the order of a few hundred Watts. This will require the super conducting proton triplet to be coated such that this extra heat does not quench the magnet.

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Element	Power [kW]	E_c [keV]
DL	6.4	71
QL3	5.3	308
QL2	4.3	218
QL1	0.6	95
QR1	0.6	95
QR2	4.4	220
QR3	5.2	310
DR	6.4	71
Total/Avg	33.2	126

Table 2: Synchrotron radiation power and critical energy in the elements of the high luminosity interaction region.

Method	Power [kW]	E_c [keV]
Geant4	33.2	126
IRSYN	33.7	126
Analytic	33.8	

Table 3: High luminosity interaction region power and critical energy comparison.

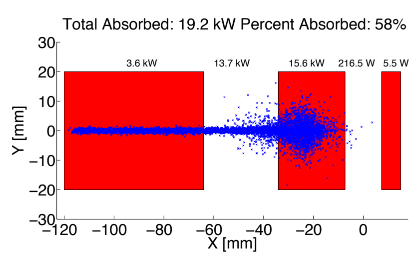

Figure 1: Power distribution on the face of the radiation absorber for the high luminosity layout.

The growth of the fan inside the interaction region also places limits on the beam pipe dimensions. This can be seen from Figure 2, where the fan is the narrowest for the HL option due to the geometry of the optics.

High Acceptance

The HA option contains the highest amount of SR power creation in the IR, for a total of 51.1 kW as can be seen in Table 4. This was computed with the G4 model.

The comparison of the G4 method with the IRSYN program and the analytic method are given in Table 5, again showing a good agreement.

The distribution of the power at the surface of the absorber is given in Figure 3. For the HA case SR leaks into the proton bore on the order of a few Watts, making coating of the super conducting proton triplet not necessary for this case.

The growth of the fan inside the interaction region also places limits on the beam pipe dimensions. As can be seen from Figure 4. The geometry of the optics for the HA case causes a slightly larger fan than the HL case. However this does not make a considerable difference.

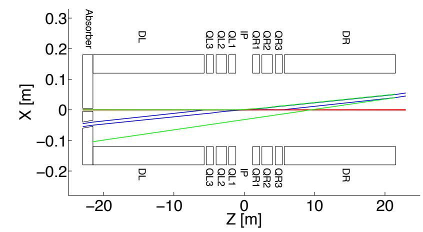

Figure 2: Radiation envelope for the high luminosity layout.

Element	Power [kW]	E_c [keV]
DL	13.9	118
QL2	6.2	318
QL1	5.4	294
QR1	5.4	293
QR2	6.3	318
DR	13.9	118
Total/Avg	51.1	163

Table 4: Synchrotron radiation power and critical energy in the elements of the high acceptance interaction region.

THE LINAC-RING DESIGN

For the Linac-Ring (LR) option there exists one IR option. The parameters are listed in Table 6.

The LR design has an amount of SR power comparable to the high acceptance ring-ring IR, and has much more than the high luminosity ring-ring IR. The SR power and E_c for the LR design are higher due to the 0.3 T magnetic fields located in the IR. The total SR power is 48.8 kW as can be seen in Table 7.

The comparison of the G4 method with the IRSYN program and the analytic method are given in Table 7.

The distribution of the power at the surface of the absorber is given in Figure 5. For the LR case SR leaks into the proton bore on the order of a few kilowatts. This will require the super conducting proton triplet to be coated such that this extra heat doesnt quench the magnet. Due to the zero crossing angle for the LR option, this causes the power continuing with the proton beam to be orders of magnitude larger than the ring-ring options.

Method	Power [kW]	E_c [keV]
Geant4	51.1	163
IRSYN	51.3	162
Analytic	51	

Table 5: High acceptance interaction region power and critical energy comparison.

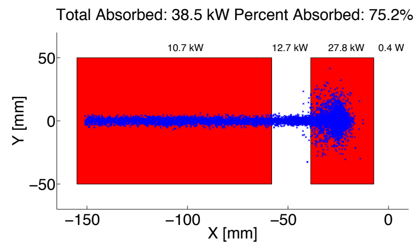

Figure 3: Power distribution on the face of the radiation absorber for the high acceptance layout.

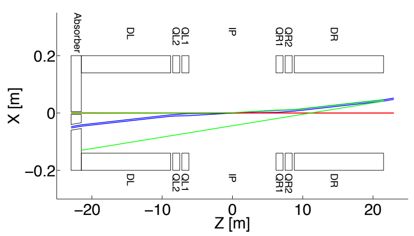

Figure 4: Radiation envelope for the high acceptance layout.

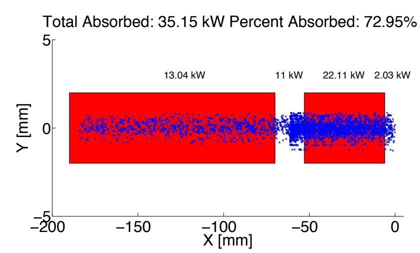

Figure 5: Power distribution on the face of the radiation absorber for the linac-ring design.

Characteristic	Value
Electron Energy [GeV]	60
Electron Current [mA]	6.6
Crossing Angle [mrad]	0
Absorber Position [m]	-9
Dipole Field [T]	0.3
Separation [mm]	75

Table 6: Linac-ring LHeC Parameters.

Method	Power [kW]	E_c [keV]
Geant4	48.8	718
IRSYN	48.8	718
Analytic	48.8	

Table 7: Linac-ring interaction region power and critical energy comparison.

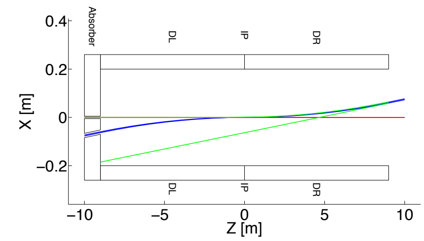

Figure 6: Radiation envelope for the linac-ring design.

The growth of the fan inside the interaction region also places limits on the beam pipe dimensions. As can be seen from Figure 6 The fan is the largest for the LR option due to the geometry of the optics.

CONCLUSION

In this paper we have developed new models and codes to study the production of synchrotron radiation in the interaction region of the LHeC. There are two design variants for the LHeC, the ring-ring and the linac-ring options, with two possible IR layouts for the ring-ring option. We have studied the SR using a G4 model, a custom-written code (IRSYN) and with analytic models, and found good agreement for SR power and average critical energy for all designs. In all the cases, the total SR power is between 30-50 kW and requires the use of special absorbers to screen critical elements and prevent reflected photons into the detectors. The layout of each IR option plays an important role in the size and intensity distribution of the SR fan inside the IR, and provides unique results for each. This is important for the downstream SC proton triplet, the size of the beam pipe, and the downstream absorber design.

REFERENCES

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