EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ACC-2013-088

Studies for the LHeC Beam Transfer System

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Presented at IPAC'2013, 4th International Particle Accelerator Conference
12-17 May 2013 - Shanghai, China

Geneva, Switzerland

July 2013

STUDIES FOR THE LHeC BEAM TRANSFER SYSTEM

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Abstract

The LHeC would allow for collisions between an electron beam from a new accelerator with the existing LHC hadron beam. Two possible configurations were studied: a separate linac (Linac-Ring) or a new electron ring superimposed on the LHC (Ring-Ring). The racetrack linac is now considered as the baseline for the LHeC design, with the Ring-Ring solution as a backup. The studies performed for the considered options are presented in this paper. For the Linac-Ring option the requirements for the post collision line and the beam dump design have been evaluated in the case of a 60 GeV and a 140 GeV electron beam. In the Ring-Ring option, studies have been performed on the optics design of the transfer line from a 10 GeV injector linac into the LHeC ring and of the injection system. The internal 60 GeV electron beam dump design has also been considered.

INTRODUCTION

The possibility of realising a collider allowing simultaneous pp and ep collisions, the LHeC, is under study at CERN [1]. For this purpose, the 7 TeV LHC proton beam could be used and a new electron accelerator should be built. Two solutions have been explored for the e beam: a linear accelerator (Linac-Ring (LR) option) or a storage ring (Ring-Ring (RR) option). For the LR option, either a recirculating energy recovery linac (LR-ERL) operating in continuous wave (CW) mode or a pulsed super-conducting (LR-SC) linac could be used. In the first case the energy would be limited to 60 GeV while the SC linac would allow operation up to 140 GeV. Due to synchrotron radiation, recirculation is not possible for the SC linac and the luminosity ($\mathcal{L}$) is $\sim$20 times lower than for the ERL linac (e beam parameters are summarised in Table 1).

Table 1: Electron beam parameters for the three accelerator options.

	RR	LR-ERL	LR-SC
Collision energy [GeV]	60	60	140
Bunch population [10^9 e]	26	2.0	1.6
Bunch length [mm]	10	0.3	0.3
Bunch interval [ns]	25	50	50
H. norm. emittance [mm]	0.58	0.05	0.1
V. norm. emittance [mm]	0.29	0.05	0.1
Repetition rate [Hz]	N/A	CW	10
Average current [mA]	131	6.4	0.3
$\mathcal{L}$ [10^{32} cm^{-2} s^{-1}]	17	10	0.4

The RR option allows reaching the highest luminosity. A new ring has to be installed on top of the LHC and a new 10 GeV electron injector, a recirculating linac, has to be built. The installation of the LHeC ring is very demanding and would require a few years shutdown of the LHC.

LINAC-RING OPTION

The studies performed on the extraction beam lines and the requirements for the e beam dump design are presented for the ERL and the SC linac.

LR-ERL Extraction Lines and Beam Dump

The ERL has a racetrack shape and is constituted of two 1 km long SC linacs and two arcs with a curvature radius of 1 km (Fig. 1). The e beam is injected at 500 MeV and gains 10 GeV at each passage through the linacs. Each arc contains three separate superimposed lines for the 10, 30 and 50 Gev beams on one side and the 20, 40 and 60 GeV beam on the other side. A vertical spreader system is installed at the end of each linac to direct the beam into the arc with the appropriate energy (Fig. 2). A specular system is used to recombine the beams at the entrance of the linacs.

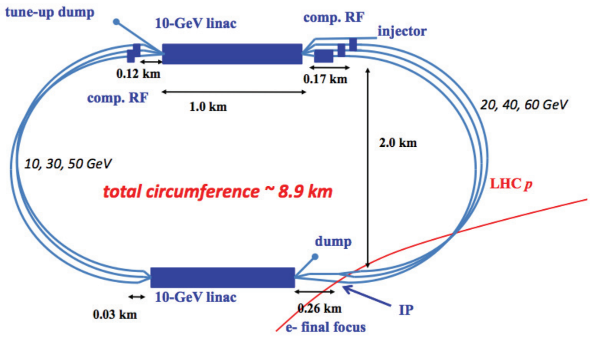

Figure 1: Schematic view of the racetrack ERL linac

After three revolutions, the 60 GeV beam is focused and put into collision with the p beam. After collision, the remaining beam is sent back through the first linac, at a decelerating phase, to convert the stored beam energy into RF energy. After three revolutions, the beam is back at 500 MeV and dumped. During nominal operation, a 6.4 mA beam current of 500 MeV has to be dumped, corresponding to 3.2 MW. The main dump is installed after the second linac, in the inner side of the ERL (Fig. 3). For commissioning and setup reasons, the option of dumping all the different energy beams is considered, for which an equivalent system should be installed at the exit of the first

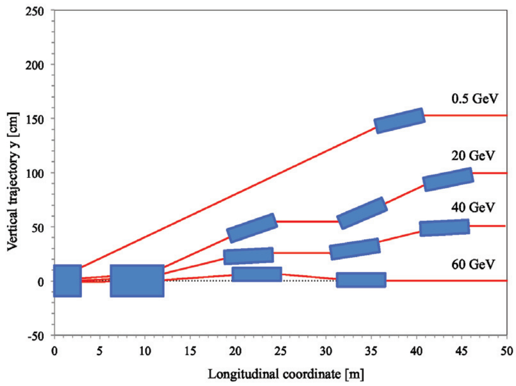

Figure 2: Vertical spreader architecture located downstream of the second linac.

linac (Fig. 1). In the following, only the studies for the main dump line are presented; analogous considerations hold for the setup dump.

The CW operation mode prevents using fast kickers to extract the beam. Instead, a system of switch magnets (one system per beam line, independently powered) has to be installed downstream of the vertical splitter, where the beams are fully separated. Calculations have been done using, as a reference, the "MBS" C-shaped switch magnets presently installed in the CNGS and HiRadMat facility beam lines (main MBS parameters in Table 2).

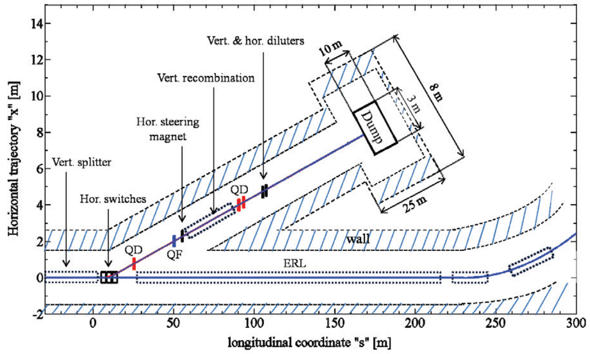

Figure 3: Schematic top view of the ERL extraction line for the main dump.

One MBS is sufficient to continuously kick the 500 MeV beam horizontally by 50 mrad (magnetic field B = 0.028 T). This kick provides enough clearance for the downstream magnetic elements of the ERL and to fit the dump cavern about 200 m downstream of the MBS. Three switches have to be used to deflect the 20, 40 and 60 GeV setup beams by the same 50 mrad angle (corresponding to a magnetic field per magnet of 0.370, 0.741 and 1.111 T, respectively). Only the switches for the selected energy will be activated during the setup; they will be off during nominal operation. The current of the setup beams is limited to 0.05 mA, which corresponds to a maximum power of 3 MW for the 60 GeV beam. Given the large range in magnetic field between 0.5 and 60 GeV, separate magnet designs (at least two types) will probably be needed for the switches.

Table 2: Parameters for the switch and the quadrupole magnets used in the extraction line.

Magnet	Max. Field [T - T/m]	Length [m]	Apert. [mm]	Width [mm]
MBS	1.7	3.0	157	900
QD/QF	10	0.25	70	540

A horizontal dipole magnet per line is used to bring the beams into the same vertical plane before recombining them in the common beam pipe to the dump (identical to the ERL recombination system). Two quadrupoles, one defocusing (QD) and one focusing (QF), are installed before the recombination region. The same hardware and FODO cell structure as in the linac are considered (QF-QD parameters in Table 2). Two additional QDs are installed ∼80 m before the dump to maximise the beam spot size at the dump entrance and thus minimise the energy density on the dump window. For a normalised emittance of 50 mm mrad (which takes into account the blowup induced by the synchrotron radiation for the 60 GeV beam) and a β function of 600 m, the spot size (1 σ) at the dump window would be ∼5 mm and ∼0.4 mm at 500 MeV and 60 GeV, respectively. A window with a 5 cm radius could fit the 10 σ beam envelope; no damage is expected during nominal operation. A combination of a horizontal and a vertical kicker magnet, powered with sin/cos frequency, is used to actively dilute the high energy setup beams on the dump window.

A 3 m^3 water dump (8 m long and 0.4 m diameter), based on the International Linac Collider (ILC) dump design [2], is considered. Shielding has to be installed around the water dump for a total volume of 3 m × 3 m × 10 m. The dimensions of the cavern (Fig. 3) were calculated considering a distance of 1.5 m between the dump and the walls to allow the passage of people and machines for installation and maintenance purposes. The possibility of having service caverns for water treatment and heat exchange has to be explored.

LR -SC Post-collision line and Dump

An ILC-like design is considered for the 140 GeV SC pulsed linac which is 7.9 km long. Every 0.1 s an electrons pulse of 5 ms collides with the 7 TeV LHC proton beam and is dumped. The post-collision line has to be designed taking care of minimising beam losses and irradiation. A standard FODO cell optics followed by strong quadrupoles and a long field-free region, which allows the natural growth of the beam before reaching the dump, are foreseen. Additional kickers are installed at the end of the line to dilute the beam and reduce the energy density at the dump window. A system of collimators is used to keep losses below an acceptable level. Nominal operation implies dumping a 50 MW beam, which is equivalent to the average power

ISBN 978-3-95450-122-9

consumption of ~70000 Europeans. An *EcoDump* could be used to recover some of this energy; detailed studies are needed and not presented here. The proposed design is based on the concept of the ILC water dump (rated for 18 MW electron beam) and linearly scaled to the LHeC requirements. The LHeC beam dump contains 36 m^3 of pressurised water (35 bar) and is 21 m wide and 36 m long, including the shielding. Preliminary calculations showed that a minimum beam size (1 σ) of 1.8 mm is required to keep the maximum temperature at the window below 100°. This corresponds to a β of 8877 m for the undisrupted beam which has an emittance of 0.37 nm. For the same β a beam spot size of 2.56 mm is calculate for the disrupted beam (0.74 nm emittance). An hemispherical Ti alloy window with a radius of 5 cm and a thickness of 2.3 mm is used to withstand the water pressure and fit the 10 σ beam envelope. Detailed energy deposition and feasibility studies have still to be performed but it is evident that dumping 50 MW will be a major challenge.

RING-RING OPTION

Simultaneous pp and ep collisions require the construction of bypasses for the e beam around the LHC experiments. The e are injected into the right side of the bypass around ATLAS. Studies were performed assuming that the 10 GeV linac injector is at the same altitude as the main ring (purely horizontal injection). A transfer line of ~900 m constituted by 15 FODO cells with a 100° phase advance is considered; the last two cells are used for optics matching. Bunch-to-bucket injection is planned (i.e. no accumulation) and several possibilities are explored.

Injection onto the Closed Orbit

A septum and a kicker are installed in a dispersion-free region of the bypass to merge the injected beam onto the closed orbit of the circulating beam (main magnet parameters are summarised in Table 3).

Table 3: Magnet parameters for matched injection and to generate a 20 mm bump for mis-matched injection.

	Magnet	Kick θ [mrad]	B dl [T m]	Length [m]
Matched	Septum	33	1.1	3
	Kicker	1	0.03	0.8
Mis-matched	Kicker1	1.35	0.04	2
	Kicker2	2.37	0.08	3.5
	Kicker3	0.55	0.02	1

The e beam bunch structure is assumed to match the LHC p bunch structure (72 bunches spaced by 25 ns). The recirculating linac cannot provide the nominal LHC train of 72 bunches; a rise and fall time of about 23 ns has thus to be considered for the injection kicker (a 2 ns jitter margin is taken into account).

Mismatched Injection

A closed orbit bump is used to bring the circulating beam orbit close to a septum. The bump is switched off before the next circulating bunch arrives. Three kickers are used to generate a 20 mm bump (magnet parameters in Table 3); the central magnet (Kicker2) is a combined kicker-septum system.

Betatron or synchrotron mismatch can be used; in the second case the kicker-septum needs to be located where the horizontal dispersion D_x is large; the beam is then injected with position and momentum offset. Synchrotron mismatch has the advantage of a shorter damping time for the injection oscillations and small oscillations in the experimental regions (large β functions but small dispersion). In both cases the rise and fall time of the kickers could be of the order of ~80 μs.

Dump system

The dump system is designed using the LEP internal dump as a reference [3]. A Carbon-composite block (0.5 m × 0.5 m × 2.5 m) constitutes the absorber. Horizontal and vertical kickers are used to dilute the beam onto the dump (100 mm sweep length). The same design as for the LHC diluter magnets (MKB) can be used. The kickers and the absorber block are located in the bypass around CMS in a dispersion-free region. Vacuum containment, shielding and water cooling systems have to be incorporated. A spoiler can be installed before the dump to provide further dilution.

CONCLUSIONS

Preliminary studies on injection and dump systems for three different options for the e accelerator of the LHeC have been explored. The design of the extraction beam line and dump system for the ERL have been defined for nominal operation and beam setup; no showstopper has been identified. A complex water dump, based on the ILC design, has been proposed for the LR-SC option. The 50 MW dump represents a real challenge and detailed feasibility studies have still to be performed. No main issues have been identified for the RR option for both the injection and dump systems. The installation of the e storage ring will have a major impact on the LHC operation. On the basis of expected performance, technological challenges and impact on the LHC operation, the LR-ERL option is nowadays considered as baseline for the LHeC design.

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