HERA STRAIGHT SECTIONS FOR HEAD ON ELECTRON-PROTON INTERACTIONS

HERA Straight Section Lattice Design Group
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Abstract

Proton and electron optics for the HERA straight sections are presented. The layout is based on a symmetric head on interaction geometry. Layout and optics have been optimized with respect to electron-proton luminosity, and by taking into account partly conflicting requirements such as: space for installation of components (detectors, injection, cavities, beam dump, ...), minimum refrigeration demand, cost minimization, background, apertures, spin rotator, spin matching, satellite resonances, and flexibility of operation.

The choice of interaction parameters results in a luminosity of $0.25 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (30x820 GeV, limited by beam-beam tune shifts). Aperture requirements for the proton magnets are discussed for both luminosity and injection conditions. For initial electron ring operation a simple spin rotator by-pass option is sketched. With the assumption that in the first stage of HERA there will be no e-p interaction in the west, the Straight Section West is modified in favour of injection and beam dump demands.

Introduction

It is currently planned that in HERA electrons and protons will collide "head on" [1,2,3] and that longitudinal polarization will be realized using the mini-rotator concept [4]. The plan to use a crossing angle has been dropped in order to avoid beam blow up due to the beam-beam interaction [5], but the HERA tunnel geometry is such that a later return to a non-zero crossing angle would not be excluded. An antisymmetric version of the mini-rotator was also considered but given up in favour of a strictly symmetric head on version with mini-rotator, which leaves more room for rf cavities.

Interaction Region

The two most important requirements for a head on collision scheme are:

a) e-p separation should be strong in order to save space for e-cavities and to allow the proton low beta quadrupoles to be close to the interaction point (IP).

b) On the other hand, the separation should be weak to avoid high synchrotron radiation power and high photon critical energy in the detector region and in the superconducting components of the proton beam line.

In order to restrict the synchrotron radiation envelope in the detector region it is desirable to have the radiation source as close to the IP as possible. It is also necessary to put the low beta e-quadrupoles as close as possible to the IP (low beta values at the IP are valuable both for e- and p-optics for matching beam sizes). Both of these requirements can be satisfied by merging the separating and focussing functions into combined function magnets. In practice, this will probably be achieved by the use of off-axis quadrupoles. We must then content with the fact that horizontal dispersion D_x is generated in a region where the horizontal beta function is comparatively large, yielding troublesome dispersion in the rf section. This latter can be minimized by the use of triplet focussing (first quadrupole horizontally focussing) which offers the additional advantage of maximum optical flexibility at the IP.

The distance between IP and the first machine magnet has been fixed at 5.8 m. The experiment equipment in the area of this magnet can extend to 5.5 m. Figure 1 shows a top view of the interaction region layout.

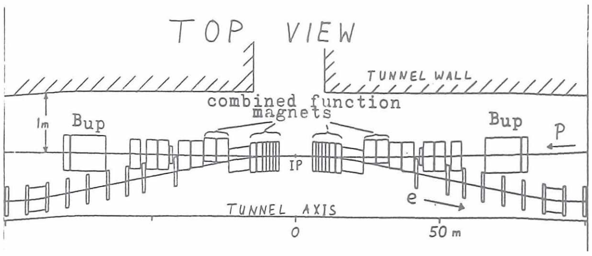

Figure 1: HERA interaction region layout ("3 alpha").

In order to achieve sufficient separation, an e-deflection angle of 10 mrad has been chosen, which had to be incorporated into the spin rotator layout [2,6]. About half of the separation angle is generated by the combined function triplet and the other half by a separate dipole (compensating the angle error if the triplet focussing is changed). The bending radius in the triplet and the dipole is 1360 m and with the expected focussing strengths, this corresponds to mounting the quadrupoles 5 mm-12 mm off-axis.

In order to avoid development of special types of superconducting quadrupoles, the low beta proton-quadrupoles are normal conducting. For technical reasons they are split into parts each 4 m long. The first two parts (out of four) of the vertically focussing low beta quadrupole are combined function magnets, too. The reason is as follows:

In order that the electron beam can pass close to the proton beam (about 8 cm only) and so that the first proton quadrupole can be as close as possible to the IP, an off-axis half quadrupole with a mirror plate must be used, and this is effectively already a combined function magnet, a fact which is very convenient, since it is clear that the angle of proton deflection in the separator magnets depends on the energy of the proton beam, eventually resulting in a kick error. This can be compensated quasi-locally in these combined function magnets.

The interaction region parameters will be:

	protons	electrons
β_x^*/m	10.	2.0
β_z^*/m	1.0	0.7
β_x^{max}/m	1030	62
β_z^{max}/m	760	390

Luminosity: $L = 0.254 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

using $N_p = 10^{11}/\mathrm{bunch}$ $\quad \varepsilon_{x,p} = 0.5 \cdot 10^{-8}\mathrm{m} = \varepsilon_{z,p}$
$N_e = 3.6 \cdot 10^{10}/\mathrm{bunch}$ $\quad \varepsilon_{x,e} = 1.6 \cdot 10^{-8}\mathrm{m} = 10\ \varepsilon_{z,e}$
(90 deg phase advance per cell)

Beam-beam tune shifts:

$\Delta Q_{x,p} = 0.0026$ $\quad \Delta Q_{z,p} = 0.0014$

$\Delta Q_{x,e} = 0.023$ $\quad \Delta Q_{z,e} = 0.026$

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Straight Sections

Figure 2 shows a top view of the HERA straight section layout. The tunnel geometry has been chosen not only to accomodate this layout but also to leave room for possible alterations such as a crossing angle at the IP, antisymmetric spin rotators or solenoid spin rotators [7]. A side view is sketched in fig. 3.

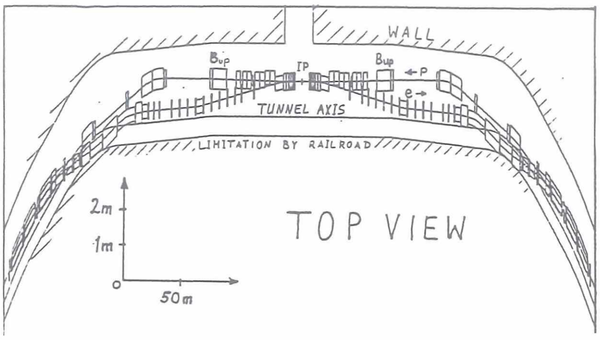

Figure 2: HERA straight section layout ("3 alpha").

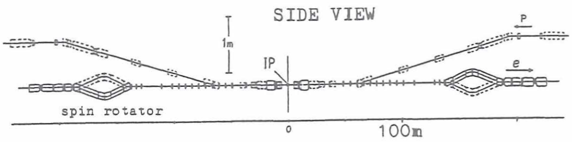

Fig. 3: Side view of the HERA straight section layout.

a) Proton straight section lattice and optics.

The design considerations for the straight section lattice of the HERA proton ring may be listed briefly as follows:

- A sufficient number of drift spaces with suitable optical parameters are needed for rf cavities, beam dump and injection.
- Non-standard aperture requirements in superconducting elements (standard: r = 28 mm) should be avoided (i.e. avoid development of nonstandard s.c. elements).
- Cold-warm adapters should be avoided if possible.
- Individually powered s.c. elements should be avoided.

The resulting luminosity optics is shown in figure 4.

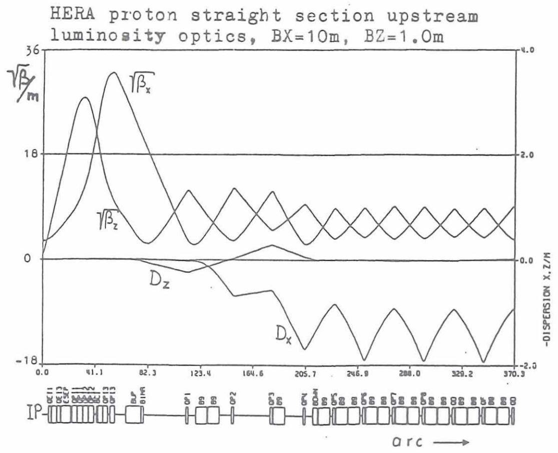

Fig. 4: HERA luminosity optics for the proton ring.

In the HERA proton ring the main dipoles and the main quadrupoles are excited by the same current. Since the focal lengths in the straight sections will be different from those in the periodic arc, this has necessitated modifying the straight section quadrupole lengths. However, it is unacceptable that the resulting optics is totally inflexible. Among others, one reason is that for:

- Injection operation:

  The largest acceptance is needed at injection energy (40 GeV). At injection, however, large ß-values and $D_x \neq 0$ are allowed at the interaction point. Thus, in order to reduce aperture requirements (especially in critical elements such as low beta quadrupoles, kickers, and s.c. elements), a special injection optics is needed. Then, the aperture requirements as scaled from the arc according to [8]

  $$Ap(s) = (Ap_{arc} - \frac{\Delta p}{p} D_{arc}^{max}) \sqrt{\frac{\beta(s)}{\beta_{arc}^{max}}} + \frac{\Delta p}{p} D(s)$$

  can be fulfilled in the whole straight section without technical complications. To make such an injection optics we need 12 variable quadrupoles per octant including the low beta quadrupoles [3]. Fortunately, the changes in most quadrupoles are so small that they can be realized using correction quadrupoles [9].

The first superconducting element in the proton beam line (as seen from the IP) would normally be the vertical bending dipole B_{up}, see figs. 1 and 2. It is seen from fig. 4, however, that this magnet needs a non-standard aperture in the horizontal direction. Furthermore, it is subject to a considerable portion of the synchrotron radiation from the e-p separator. Development of a special, warm bore dipole can be avoided if this magnet is also normal conducting.

b) Electron straight section lattice and optics.

The most important design considerations are as follows:

- The low beta insert and electron-proton separation must be combined.
- Small $\beta_{x,z}$ and dispersion D_x in the rf section must be obtained. A periodic FODO channel with 5.9 m drift spaces must be provided for normal conducting as well as super conducting cavities.
- The electron spin rotator must be incorporated.
- Spin matching condition including a horizontal and vertical betatron spin match and a horizontal dispersion spin match must be satisfied in order to control various depolarizing effects [10,11].

With the use of the combined function magnets, the dispersion spin match, which consists essentially of ensuring that the total change in D_x' caused by the quadrupoles is zero across the whole interaction region, can be seriously violated. Furthermore, with zero horizontal dispersion at the IP the separators prevent D_x from being zero in the rf region (see section II). In the present proposal the dispersion match has been reestablished with the help of the additional dipole in the rf section and it has also been possible to limit $|D_x|$ to less than 20 cm in this region which should be acceptable.

During the first stage of HERA operation it is likely that only one straight section will be equipped with its pair of mini-rotators. In the other straight sections each rotator could be easily replaced by a single dipole magnet and by making only very slight modifications to the optics. Alternatively, one could install a simple lattice with a smooth optics covering the whole rotator region.

The resulting electron luminosity optics is shown in figure 5.

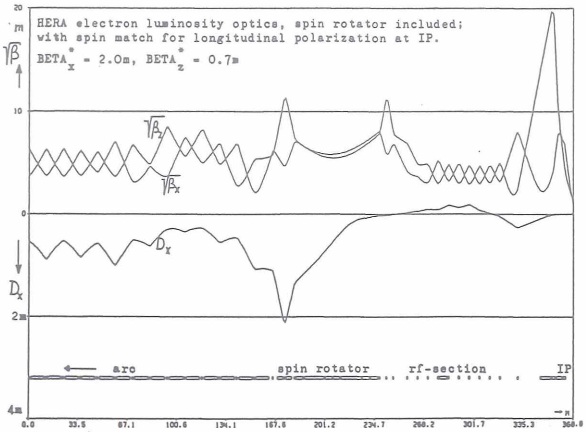

Figure 5: HERA electron luminosity optics, spin rotator included. with spin match for longitudinal polarization at IP.

- Injection operation:

  Spin match conditions and luminosity requirements at the interaction point may be dropped at injection energy.

HERA Straight Section West

If there were no e-p interaction in the West Straight Section in the first stage of HERA, considerable simplification could be achieved by optimizing the layout in that straight section with respect to injection and beam dump demands. This could be particularly valuable during the commissioning stage and could be dropped in later HERA completion stages.

Figure 6 shows a top view of such a HERA Straight Section West layout.

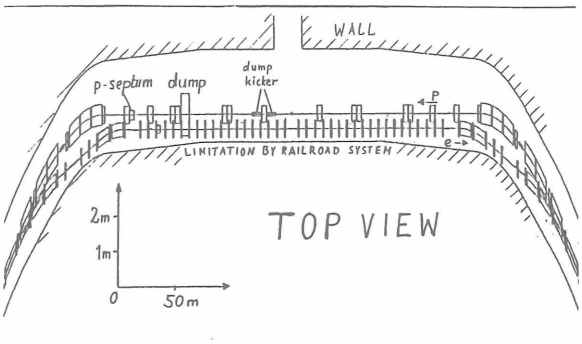

Figure 6: HERA Straight Section West (without e-p interaction).

Since all low beta and separation magnets as well as vertical deflections of protons are omitted, there is plenty of drift space for beam dump and injection. As a consequence, more transverse clearance between the injected proton-beam and superconducting elements is achieved and kicker strengths can be considerably reduced.

As seen from figure 7, the proton optics in the Straight Section West is rather smooth.

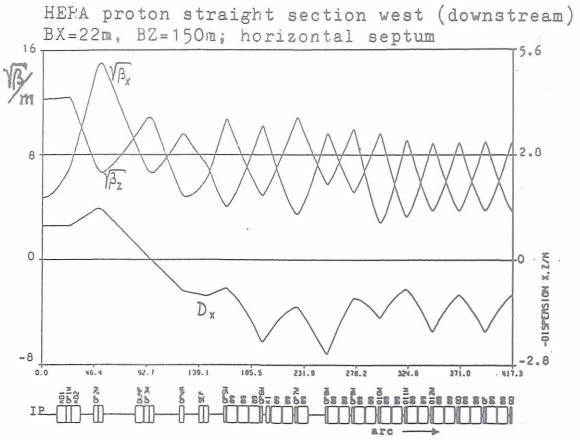

Fig. 7: HERA Proton Straight Section West (downstream)

In the electron ring, there is also plenty of additional space for extra rf cavities, if they are needed at this stage. Last but not least, the possibility of easier installation of beam dump, injection, and electron-rf components would be much appreciated.

Acknowledgement

Continuous fruitful discussions with G.A. Voss and other members of the HERA Planning Group contributed to the design as presented in this note.

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