OPTIMISING THE INJECTION SCHEME FOR DIAMOND FROM A 3GeV BOOSTER SYNCHROTRON

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Abstract

The proposed 3GeV light source DIAMOND will utilise a full energy injector synchrotron operating at a frequency of up to 10Hz. A requirement of the injection scheme is to minimise the space allocated to its components that could otherwise be exploited for synchrotron radiation output. A multi-turn system using four kickers in a single straight has been compared with the alternative, but less attractive, distributed kicker scheme relying on the lattice quadrupoles to create the required injection bump amplitude; high energy light sources elsewhere have been forced to adopt the latter solution. The associated septum magnet specification has also been assessed. At 3GeV both schemes make significant demands on the pulsed septum and kicker magnet technology. The consequences for the necessary properties of the extracted beam from the booster are also examined.

1 INTRODUCTION

Nearly all third-generation light source storage rings in design or operation utilise multi-turn injection [1]; this method allows accumulation of stored current from multiple pulses from an injection system, usually a booster synchrotron or linac operating with repetition frequencies ~Hz. Injection always takes place into the horizontal phase space, to allow the smallest possible vacuum chamber height for insertion devices.

Injection schemes in third-generation light sources may be divided into two groups: lower-energy machines, up to energies of about 2.5 GeV, usually place all the kicker magnets in a single straight section (e.g. Elettra [2] and BESSY-II [3]). This scheme has the advantage that the bump produced is independent of the working point, and if a symmetrical 4-kicker bump is used all kickers can be powered together to the same field strength, giving better stability of the bump. For higher-energy machines, it is not generally possible to make kicker magnets with sufficient bend angle for the straight length usually available (e.g. APS[4], ESRF[5]), so kickers are instead distributed elsewhere in the lattice to allow a larger bump size from a given kicker field.

DIAMOND occupies a middle position at 3GeV, and so it is not immediately clear whether the single straight scheme is possible in the 5m straight length which is available. Both the kicker distributions described above have therefore been considered for the DIAMOND lattice.

2 SINGLE-STRAIGHT SCHEME

2.1 Space Allocation

The present DIAMOND lattice possesses two very long racetrack sections (~20 m), and 14 other straights each 5m long, 6 with high radial β-function (15m at the symmetry point) and 8 with low radial β-function (1m at the symmetry point). Since it is not desirable to utilise the racetrack straights, the injection scheme must utilise a standard 5m straight. Space restrictions among the lattice elements (to constrain the overall machine circumference) mean that it is not possible to place kicker magnets among the matching quadrupoles or in the achromat, so the scheme must occupy at most the 5m space in the straight. When compared to other low-energy light sources, this is a very stringent requirement.

2.2 Injection Scheme

Injection takes place into the horizontal phase space. Four kicker magnets produce a symmetrical bump, a septum magnet being placed at the centre of the bump (Figure 1). Four kicker magnets are used (as opposed to three) to reduce the peak kicker field requirement. Placing the septum between kickers 3 and 4 would reduce the septum field requirement by about 15%, but would require an unacceptably large space between kickers 1 and 2; this latter option is therefore discounted.

The minimum required bump amplitude is calculated following S.Tazzari [5], optimally matching in horizontal phase space when the horizontal β-function of the injected beam, β_i, satisfies

$$\beta_i^2 + \left(\frac{n\sigma_i + T}{2\sqrt{\varepsilon_i}}\right)\beta_i^{3/2} = \frac{\beta_0^2}{2}, \qquad (1)$$

where β_i, β_0 are the horizontal β-functions of the injected beam and stored beam at the septum end, ε_i, σ_i are the injected beam emittance and horizontal injected beam size, and T is the effective septum thickness (5mm, assuming a generous position tolerance of ±1mm). 6σ of injected beam (i.e. n=6) is provided for to allow for steering errors (the optimum radial β-function is also overestimated by a factor of 2 to allow for non-linearities). The required bump amplitude is then

$$A = T + n\sigma_i, \qquad (2)$$

assuming no dispersion in the injection straight. Closed-orbit errors will be managed by having a movable septum and using first-turn steering. With the present booster design emittance of 118nmrad [6], this gives a minimum required bump amplitude of 10.8mm. The kickers are specified to give an allowance of 20% above this requirement. Sufficient radial aperture in the bump region is provided for with a wider vacuum chamber in the injection straight.

A conflict arises between the space required to produce the required kicker bump amplitude, and the space required for a sufficient bend in the septum to allow the injected beam to clear kicker 2. The best compromise is to utilise a single 3mm septum magnet; the field of 0.8T produces a bend angle in the injected beam of 96mrad (5.5°, magnetic length of 1200mm). The solution also requires a high peak kicker field of 0.24T (magnetic length 550mm, bend angle 13.2mrad); however, kicker fields at this level are believed to be feasible [3].

To prevent loss of injected beam against the vacuum chamber due to betatron oscillations, the injection elements must be in a high radial β straight, the septum magnet must be positioned at a horizontal half-aperture of no more than 16mm (with the present optics [7]). The optics also place a fundamental limit on the emittance from the booster, restricting it to be under 175nmrad [6]. The septum will be movable to maximise the gas lifetime after injection - it will also allow flexibility when changing machine optics, and protect the septum from synchrotron radiation. With sensible working points, four storage ring revolutions (4.6μs) are allowed before betatron oscillations bring the newly injected beam back to the septum in horizontal phase space; the present radial working point is 18.73 [7]. The kicker magnets must therefore switch off within this time.

The single-straight layout is shown schematically in Figure 1; the overall length required is close to the space limitations of the straight.

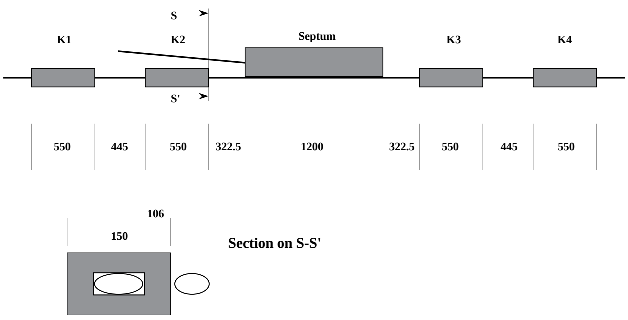

Figure 1: Single-straight layout (all dimensions are in mm). The total length is nominally 4935mm (more must be added for the physical dimensions of the end kicker vessels and flanges).

3 DISTRIBUTED SCHEME

3.1 Considerations

Similar to the single-straight scheme, any distributed injection scheme cannot utilise the very long straight sections. The distributed scheme therefore consists of kickers in three consecutive straights, the septum lying in the central, high radial-β straight. Additionally, the impact of a distributed scheme upon insertion device placement must be minimised. Kicker magnets in the outer straights must be placed toward one end of the straight, so that the remaining space may still be used for an insertion device; alternatively, it may be possible to place the RF cavities in the same straights as the outer kickers, provided that they are arranged so that the cavities do not lie within the region of the injection bump [8].

It must be ensured that there is sufficient aperture in the achromat sections for the distributed bump. The distributed injection bump needs at least three kicker magnets to cope with different working points.

3.2 Choice of Scheme

Two schemes have been considered, using either three or four kicker magnets. In both, a single (outer) kicker is placed in each of the low radial-β straights adjacent to the septum straight; either one or two kickers are placed in the septum straight. Creating sufficient bump amplitude is straightforward with either scheme provided the outer kickers lie toward the straight end nearer the septum; this placement is also favourable since the remaining straight length of the outer straights can be used for RF cavity placement. However, with the three-kicker scheme there is a large orbit displacement in the septum straight matching quadrupoles, requiring an unacceptably large aperture; the three kicker option is therefore discounted. The four-kicker scheme, using a symmetrical bump about the septum straight centre, may be tolerated; the bump profile is shown in Figure 2. The most restrictive aperture is in the F-quadrupoles adjacent to the septum straight. With a 1mm final septum, the minimum required half-aperture in the quadrupole, given by

$$A = B + S\sqrt{\frac{\beta_r}{\beta_0}}, \tag{3}$$

is 35mm, where B is the bump amplitude at the F-quadrupole, β_r the maximum radial β-function in the F-quadrupole, and S=16mm is the half-aperture required by the injected beam at the injection point; the required aperture may beaccommodated in the quadrupole design. With a thicker final septum more aperture is required in the F-quadrupole. As with the single-straight scheme, closed orbit errors are handled with first-turn steering.

The scheme uses four kickers of the same design. Using equation (2), the required bump amplitude is 8.6mm; the fields used to provide this are summarised in Table 1. The kicker strength is again over-specified to allow for different working points, a reasonable kicker specification being 100mT for all four magnets. To provide sufficient bend angle to clear the kicker in the septum straight two septum magnets must be used, a 1mm final septum operating at 0.3T preceded by a 3mm, 0.8T septum. The septum parameters are given in Table 2.

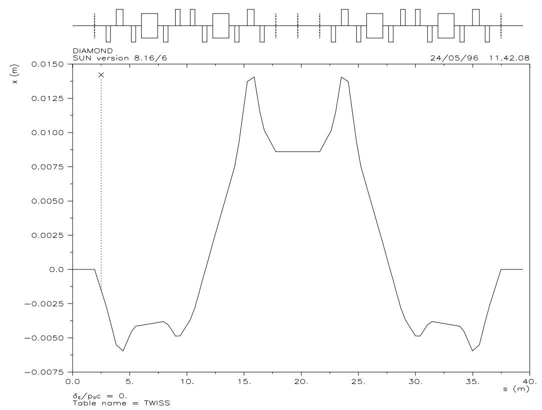

Figure 2: Bump profile for the distributed injection scheme. Injection elements are shown as vertical lines.

Table: 1 Fields and bend angles for the four-kicker scheme, giving the required 8.6mm bump. The magnetic length of the kickers is 550mm.

Position	Field Strength /mT	Bend Angle /mrad
Outer	49	2.65
Inner	28	1.56

Table: 2 Fields and lengths for septum magnets in the distributed scheme.

Septum	Field Strength /T	Length /m
3mm	0.8	1.0
1mm	0.3	0.8

4 LAYOUT CONSIDERATIONS

In deciding between alternative schemes the effect of the injection scheme upon other lattice elements is important. In the single straight scheme it will not be possible to place correction elements in the injection straight, similar to the Elettra design [2]; space for vacuum system elements will also be severely restricted. Although kicker fields of 0.24T are believed to be feasible, the safety margin of 20% which is possible is small. The conclusion is that a single straight scheme at 3GeV is not recommended in the typical straight lengths of 5-6m available in 3rd-generation sources.

The requirements of the distributed scheme are much more relaxed, although the required apertures are larger. It is straightforward to supply the required bump amplitude with kickers of modest strength, and a large safety margin can be provided for in their design. Although detailed work on the septum magnets has not yet been performed, it is clear that the distributed scheme is much simpler to implement, and is the option presently planned for DIAMOND.

5 CONCLUSIONS

With the 5m straight space available for injection elements in DIAMOND, a distributed scheme is the most realistic option available, and does not restrict the placement of other lattice elements. Although the number of straights occupied is greater, it may be possible to offset this by placing the RF cavities in the outer straights.

For a general 3GeV lattice design it is not immediately clear whether the single straight or distributed scheme is to be preferred. With a longer straight length injection into a single straight becomes realistic, and gives the important advantages of reduced magnet apertures and straight requirements.

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