THE ELETTRA LINAC-TO-STORAGE RING TRANSFER LINE

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Abstract

The injection system for the ELETTRA storage ring is a full energy linac instead of a booster. It will be located underground outside the storage ring so as not to interfere with the expermental area. It will be constructed and operated in three stages 0.6 GeV (for early storage ring commissioning), 1.5 GeV (for initial user operation) and 2 GeV (for final operation). The detailed design of the linac-to-storage ring transfer line has been completed, taking into account the need to inject beams at different energies. The design has been optimized to reach small beam sizes, and hence small magnet apertures, with a minimum number of standard magnetic elements. Since the beam size is dominated by energy spread rather than emittance, achromatic arcs are used for the 3 horizontal and 2 vertical deflections.

Introduction

The injection systems commonly used for second and third generation synchrotron light sources consist of a preaccelerator and a booster synchrotron. At Sincrotrone Trieste, a full energy linac (2 GeV) is now adopted, instead of the previous linac-booster injection system [1], in order to use the linac not only for injection but also for other purposes [1].

A new transfer line has been designed considering the following requirements :

• the linac will be located outside and below the storage ring

• the axis of the linac is tangential to the storage ring building. The distance from the center of the machine to the tangential point should be $Y_0 = 65$ m.

• The transfer line has to be underground to leave the space for the experimental hall

• the injection has to take place in the horizontal plane and from the inner side of the storage ring with an injection angle not exceeding 10 degrees

• the degree of symmetry has to be as large as possible to get as many as identical elements (bending magnets and quadrupoles), and thereupon get a small number of power supplies

• the beam size in the transfer line should be as small as possible to reduce the cost of the different elements

• in order to get bending magnets with small physical dimensions it was choosen to have high magnetic induction (1.5 T)

• the gradients in the quadrupoles should not exceed 22 T/m. This means that with an aperture of ± 25 mm the magnetic field at the poles is 0.55 T

According to these requirements the structure of the transfer line (see figure 1) consists of 4 parts :

1) the section between the end of the linac and point A, where a horizontal deflection of 2φ takes place. According to the linac energies, the length of this part is 13 m (2 GeV), 32 m (1.5 GeV) and 64.5 m (600 MeV)

2) the horizontal section between the points A and B, with a horizontal deflection angle φ at point B

3) betwen the points B and C we have the vertical section where is performed the vertical deflection at the points V and W with a deflection angle φ. The distance between points V and W is $L_0 = 19.5$ m

4) the injection section between point C and injection point I with a deflection angle φ

The accurate value of the deflection angle φ is determined by the distances Y_0, R_0 and the length L_0 of the path between the points B and C. L_0 is mainly given by the amount of quadrupoles which are needed for the matching of the vertical section to the adjacent part of the transfer line.

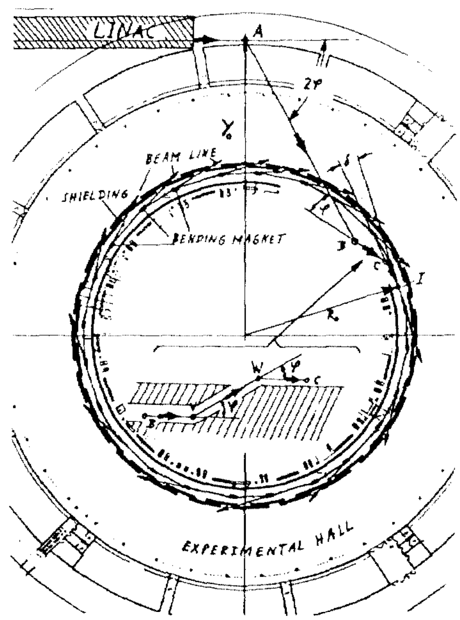

Figure 1. The storage ring building with the position of the linac and the path of the transfer line.

Preliminary design of the transfer line

The emittance of the electron beam from the linac is ε (1.5 GeV, 80%) = 0.136 π mm.mrad and the energy spread is $\Delta p/p$ (1.5 GeV, 90 %) = 1.2 %. With beta functions of 50 m the beam sizes are ± 4.1 mm and with dispersion functions D(s) = 1.4 m one gets ± 17 mm. This means that the cross section of the beam in the transfer line is mainly given by the energy spread. Hence, most parts of the transfer line have to be dispersion free. This is only possible by performing the deflections with achromatic arcs.

The simplest form of an achromatic arc with a deflection angle φ consists of two bending magnets (angles $\varphi/2$) with a quadrupole in between [2]. In this case, the largest allowed strength of the quadrupole (k-value) determines the distance between the quadrupole and the adjacent bending magnets. The horizontal deflections at points A and B are performed using such achromatic arcs.

For the transfer line from the linac to point B, identical cells can be used at each side of A. This means that most of the quadrupoles will have the same excitation and only two power supplies are necessary to power them.

For these regions, different structures (triplet, doublet and FODO) have been investigated. The FODO structure has been choosen because it uses the smallest number of quadrupoles and the lowest gradients.

The vertical deflection is built up with two magnets, with a deflection angle φ each, one to bring the beam up, the other to put the beam to the level of the storage ring. In such structure, one needs at least two quadrupoles between the bending magnets to obtain an achromatic arc [2]. For matching reasons and in order to get a good flexibility a quadrupole in the middle of the arc has to be added. This quadrupole affects only the beta functions but not the dispersion function.

To decrease the contribution of the energy spread to the beam size, the dispersion functions have to be as small as possible. On the other hand, for matching reasons the beta functions in horizontal and vertical plane should not exceed 25 m at the end of the arcs and the difference between both should be as large as possible. The space between the quadrupole and the bending magnets is given by the compromise between these two requirements.

To build up an achromatic arc with suitable values for the beta and dispersion functions in the last part of the transfer line (injection section), three quadrupoles are needed between the bending magnet at point C and the injection septum. The lattice functions of the storage ring at the position of the septum are $\beta_x = 8$ m, $\alpha_x = -0.09$, $\beta_y = 3$ m, $\alpha_y = -0.25$ and $D = D' = 0$.

Normally, a matching has to be performed to these values, but in order to get a smaller bump at the kickers it might be worthwhile making a matching to $\beta_x = 4$ m [1]. Furthermore, the injection efficiency is a function of the size of the injected beam and therefore the injection section of the transfer line must have a high degree of flexiblity. Thus, it should be possible to match the phase space of the injected beam to β-values between 2 m and 10 m. To get this high flexibility one needs at least three quadrupoles between the vertical and the injection section.
The matching between the horizontal and the vertical section can be done with three quadrupoles and four quadrupoles are needed for matching the entrance of the transfer line to the exit of the linac.

Lattice functions and beam sizes

The whole transfer line within ELETTRA facility is shown through figures 2, 3 and 4. Considering together all the bending magnets then a total deflection of 180° could be performed and with 32 quadrupoles the transfer line has twice as much quadrupoles as in the designed booster synchrotron [1,3].

The beam envelopes show four prominent peaks : in the middle of the achromatic arc at the point A ($E_x = 11$ mm), in the vertical section at the position of two quadrupoles ($E_y = 13.5$ mm) and in the injection section at a quadrupole position again ($E_y = 11$ mm). All these large beam sizes are due to the energy spread of 1.2 % (90 % of particles). For the whole beam ($3\sigma = 99.7$ %) this value has to be multiplied by a factor 3/1.64 = 1.83, so an aperture of $\pm$ 25 mm and $\pm$ 20 mm for horizontal and vertical plane, respectively are needed. With such a vertical aperture, 2 % of the particles will be lost, which should be acceptable.
To overcome this loss, one can change the circular shape of the vacuum chamber in the quadrupoles into an elliptical form, or alter the structure of the considered section line by moving the quadrupoles as close as possible to the the bending magnets and insert some more quadrupoles.
Whilst in the dispersion free regions, the beam envelope is much smaller, and the whole beam needs a space of ± 4 mm only.

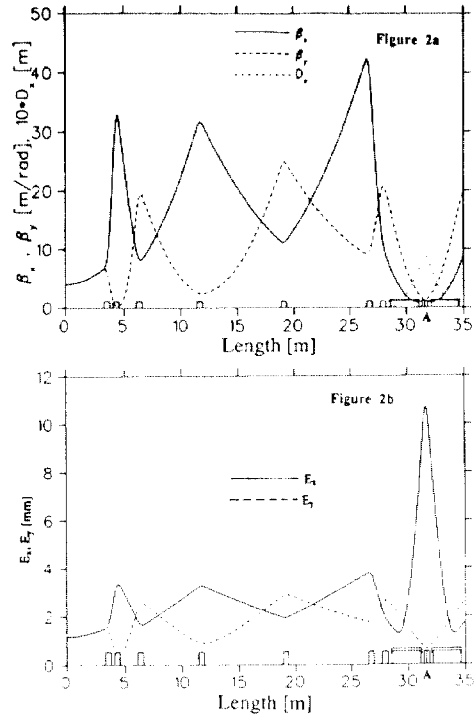

Figure 2. Lattice functions (2a) and beam sizes (2b) of the linac section (1.5 GeV linac).

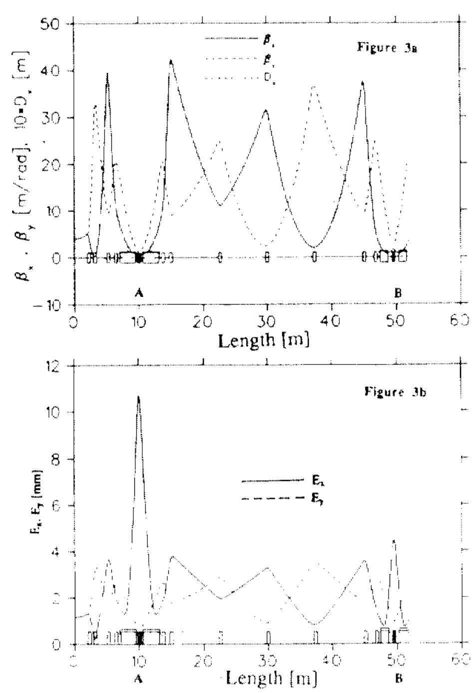

Figure 3. Final lattice functions (3a) and beam sizes (3b) through the transfer line from the 2.0 GeV linac to the horizontal deflection at point "B". The bending magnets have deflection angles of 31.4 degree (point "A") and 15.7 degree (point "B").

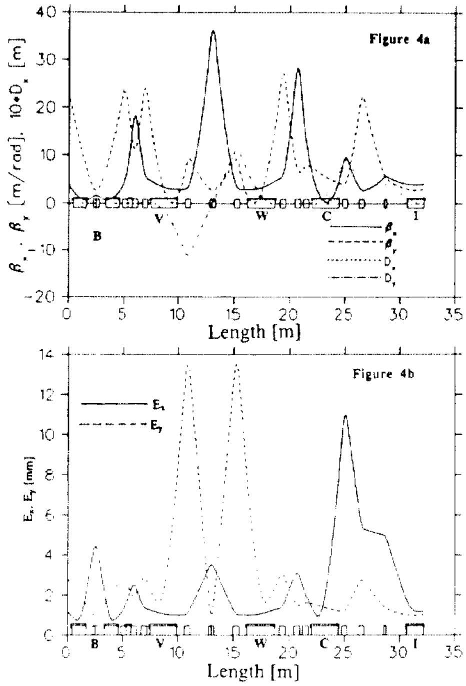

Figure 4. Final lattice functions (4a) and beam sizes (4b) trough the vertical and injection section of the transfer line build up with 31.4 degree bending magnets.

For the positrons the emittance is ε (2 GeV, 95%) = 1.2 π mm.mrad and the energy spread is Δp/p (2 GeV, 80%) = 1.2 % [4,5]. The cross section of the beam is roughly ± 9 mm in the dispersion free sections of the transfer line and ± 40 mm where the dispersion function has its maximum. Without changing the vacuum chamber , then within an aperture of ± 20 mm, 6% of the beam will be lost which should be acceptable.
The peaks of the dispersion function occur in the neighbourhood of the 31.4 ° bending magnets. Within the achromatic arcs at point 'A' and in the injection section its value is 0.9 m. Having an aperture of ± 20 mm, an energy spread of ± 2.2 % for the positron beam is acceptable since 98 % of the particles can pass the transfer line. To have the same situation in the vertical section, the aperture has to be increased to ± 25 mm, which should be possible.

According to the chosen symmetry, each 31.4 ° bending magnet can be replaced by two 15.7 ° bending magnets. The lattice function for this case are similar to the previous ones, but the flexibility of the transfer line will be reduced.

References

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