

THE INJECTION SYSTEM FOR THE ISI-800 STORAGE RING

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Abstract. The injection system for the ISI-800 storage ring consists of a 120 MeV electron linac, the transfer line (about 12 m) from the linac to the storage ring and three kicker magnets and a septum magnet for electron injection on equilibrium orbit. Typical injection conditions will be a peak current of 100 mA with a pulse width of $0.03\pm 0.3\mu\text{s}$ at a repetition rate of 1 or 3 Hz. The magnetic lattice of the transport line is made up of a vertical achromatic translation which brings the beam from the underground linac to the ring level, and a horizontal 90° achromatic arc including a septum magnet. The dipole and quadrupole magnets of the transfer line are designed and presented.

THE BEAM TRANSPORT LINE

To inject electrons into the ISI-800 storage ring [1] we intend to use the linear accelerator LUE-120 being designed at NSC KIPT. Its principal parameters are listed in Table 1.

Table 1. Principal parameters of the electron linear accelerator LUE-120

Parameter	Value
Electron energy, MeV	120
Pulsed current, A	0.1
Pulse rate, Hz	1,3, 6
Beam current pulse length, ns	30...300
Beam emittance at exit point, mm-mrad	0.2
Energy spread, %	0.3
Bunch length, ps	5
Operating frequency, GHz	2.797
Number of accelerating sections	2
Length of accelerating section	3.2
Total accelerator length, m	7.5

The choice of the electron linac functional scheme much depended on the requirements of facility compactness as a whole and the possibility to form a precise phase volume of the beam. An RF gun will be used as an injector; it will be able to operate under both thermal and photon emission conditions through the use of an external laser. The beam as a sequence of electron bunches from the RF gun comes to the magnetic compressor, which separates the central part of the bunch, shapes it further along the longitudinal axis and directs immediately to the accelerating sections, where the electrons are accelerated to an energy of 120 MeV.

The main requirements to the line of beam transport from the linear accelerator LUE-120 to the storage ring ISI-800 are as follows:

- beam transfer from the LUE-120 exit point to the septum-magnet without losses;
- agreement of beam emittance at the LUE-120 exit point with the acceptance of the ISI-800 ring structure;
- the electron beam size at the entrance of the septum-magnet should not exceed ± 2 mm in both coordinates;
- separation of the beam with an energy spread $\Delta E/E \leq 0.3\%$ from the bunch formed by the LUE-120, should the need arise.

The beam trajectory is determined by four dipole magnets, each with a beam bending angle of 41.5° . Two of the magnets provide the beam translation in the vertical plane, and the other two magnet together with the septum magnet of the beam injection system perform the achromatic bending through 90° . As a result, the median plane of the ISI-800 storage ring is located about 3.7 m higher than the accelerator axis.

The translation is accomplished through the use of a traditional symmetric three-lens dispersion-free scheme that imposes less rigid requirements on the stability of electromagnet-equipment power supply. The collimator-monochromator located close to the beam dispersion maximum ensures the required beam energy spread as the beam is injected to the storage ring.

Fig. 1 shows the envelopes of particles in the transport line computed with the TRANSPORT code [2]. Note that the transverse dimension of the beam in the transport line with the particle

Table 2. Main parameters of the transport dipole magnet

Parameter	Value
Magnet induction in the gap, T	1.0
Gap size, mm	40
Effective angular size in the magnetic field, degree	41.5
Axial pole length, mm	289.5
Rated energizing current, A	500.
Rated voltage drop, V	6.
Numbers of turns in the winding	72
Average length of the turn, m	0.9
Copper tube as a conductor, mm	8x8- \varnothing 4.5
Weight, kg	180

energy spread $\Delta E/E = \pm 0.3\%$ does not exceed ± 0.5 cm (for an assigned vacuum chamber aperture value of $\varnothing 4$ cm). The main parameters of transport dipole magnets are listed in Table 2.

The beam in the transport line is focused by means of 9 quadrupole lenses, whose principal parameters are

given in Table 3. Its trajectory in the transport line is corrected with four two-coordinate dipole correcting magnets. In addition, the dipole magnets incorporate a 2% correction winding. The total length of the transport lines is 11.7 m.

Table 3

Main parameters of the quadrupole lens in the transport line

Parameter	Value
Magnetic field gradient, T/m	19
Aperture diameter, mm	40
Pole-face length, mm	100
Rated energizing current, A	500
Rated voltage, V	0.2
Number of turns in the winding	16
Conductor cross-section 8×8-Ø4.5, mm ²	48
Quadrupole lens weight, kg	30

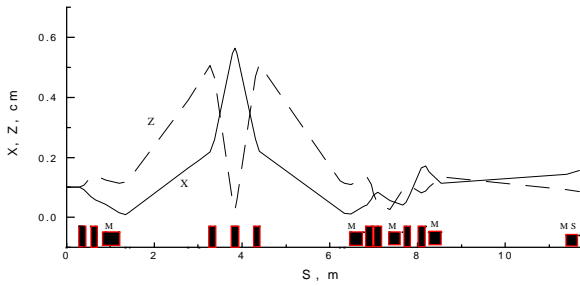


Fig. 1. Envelopes of particles in the transport line

INJECTING SYSTEM

The beam injecting system is the terminal part of the beam transport line whose main function is to transfer the electron beam to the circular track of the ring without losses and with minimum emittance distortions. This is achieved by the use of a septum magnet and pulsed magnets, i.e., kickers [3].

The injection to the ISI-800 storage ring is performed at a beam energy of 120 MeV. In this case the magnetic field induction in the bending magnets of the storage ring is $B_{inj.} = 0.1995$ T, and the betatron dumping times are $\tau_x = 2.61$ s, $\tau_z = 4.11$ s. The injection scheme was chosen to be radial; this allows one to reduce the vertical gap in the bending magnets, and therefore, to diminish the magnetic field volume and the power consumed by the device as a whole. At the beam injection point, a pulsed local perturbation of the equilibrium orbit is induced by three kickers. The displacement Δx and the beam bending angle $\Delta x'$ at the point s due to the kicker impact at the point i are given by the following expressions [4]:

$$\Delta x(s) = \sqrt{\beta_i \cdot \beta_s} \cdot (\sin \Delta \varphi) \cdot \Delta x'_i,$$

$$\Delta x'(s) = \sqrt{\frac{\beta_s}{\beta_i}} \cdot (\cos \Delta \varphi - \alpha \cdot \sin \Delta \varphi) \cdot \Delta x'_i, \quad (1)$$

where β_i, β_s are amplitude functions of the storage ring at points i and s , respectively;

$\Delta \varphi = \varphi_s - \varphi_i$ is the betatron phase advance between points s and i ;

$\Delta x''_i$ is the kicker impact force at point i ;

α is the Twiss parameter.

For providing local offset (bump) of the equilibrium orbit by the b value by means of three kickers, we can easily deduce from (1) the requirements on the "force" values of all three kickers:

$$\Delta x'_1 = \frac{b}{\sqrt{\beta_1 \cdot \beta_2} \cdot \sin(\varphi_2 - \varphi_1)},$$

$$\Delta x'_2 = \frac{b \cdot \sin(\varphi_1 - \varphi_3)}{\beta_2 \cdot \sin(\varphi_3 - \varphi_2) \cdot \sin(\varphi_2 - \varphi_1)}, \quad (2)$$

$$\Delta x'_3 = \frac{b}{\sqrt{\beta_2 \cdot \beta_3} \cdot \sin(\varphi_3 - \varphi_2)}.$$

Diagrams of the first superperiod for storage ring and the shape of the equilibrium orbit during injection are presented in fig.2. The bump is produced by three kickers, two of which are located in the straight line part of the ring, and the third kicker is situated in the first quadrant. The bump in the injecting azimuth is 15 mm, the coordinate of beam output from the septum magnet is 25 mm; this would provide a 10 mm amplitude of radial betatron oscillations after injection. Taking into account the storage ring characteristics, namely, the behaviour of structure functions and the location of kickers, i.e., the betatron phase advance between them the impact force of kickers (2) required to set up the mentioned bump at a beam energy of 120 MeV is calculated to be $B \cdot l = 0.003$ T·m.

As kickers in the ISI-800, we intend to use the quasi-matched Helmholtz coil [5], which is a double one-turn coil loaded with a 50 ohm resistor. With this induction system, pulsed current $I = 400$ A and voltage $U = 20$ kV amplitudes would be required to generate the magnetic field in the orbit, $B_z = 0.005$ T, for typical sizes of $2 \cdot a = 35$ mm, $2 \cdot b = 50$ mm, that are specified by the vacuum chamber shape.

To avoid increase in the effective beam emittance, it is necessary to ensure a synchronous switch-off of the kickers with given delay times. At the instant the injection pulse terminates the kicker being the first down beam is coming to be shut off. Then with delays of $\tau_{12} = S_{12}/c = 9$ ns and $\tau_3 = S_{13}/c = 21$ ns with respect to the first kicker the second and the third kickers, respectively, are coming to be turned off. Here S_{ik} is the distance along the beam orbit from the i -th to the k -th kicker, c - is the speed of light. The total switch-off time

should not exceed the time of particle flight from the third kicker to the first one, for the ISI-800 this would be 130 ns. Fig.3 shows the time diagrams of injecting system components operation.

At a radial betatron oscillation frequency $\nu_x = 4.26$ a two-turn injection is possible, because it is only at its third turn that the injected particle comes back to the septum magnet. Fig.4 depicts the central trajectory of the injected beam for its first three turns. The linac pulse duration for the two-turn injection must be equal to the double period of electron rotation in storage ring and is found to be 310 ns in our case.

The main parameters of the septum magnet are presented in Table 4.

Table 4 Main parameters of the septum magnet in the injecting system

Parameter	Value
Magnet induction, T	0.18
Operation region (height×width), mm	20×25
Magnetic circuit length, m	0.3
Magnetic field inhomogeneity, %	±0.3
Septum thickness, mm	1

REFERENCES

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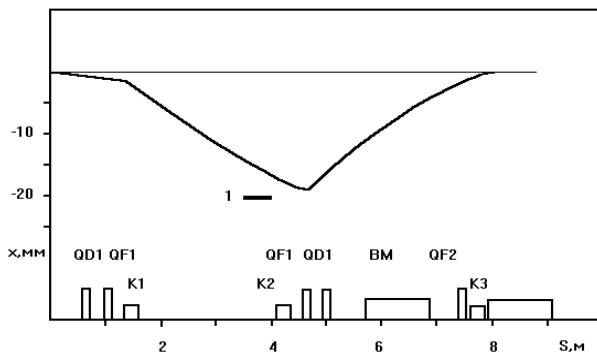


Fig.2. Equilibrium orbit distortion at the instant of injection
(QD, QF, BM - storage ring regular lattice, K1-K3 - kickers, 1 - septum magnet knife)

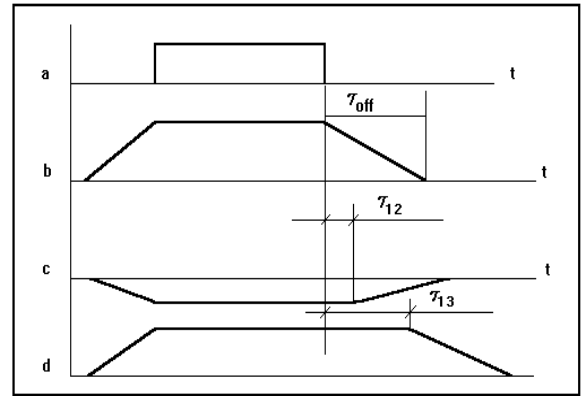


Fig.3. Time diagrams for operation of injecting system elements

(a - linac pulse, b, c, d - pulses of kickers 1, 2 and 3, respectively, τ_{off} - switch-off time, τ_{ik} - delay times)

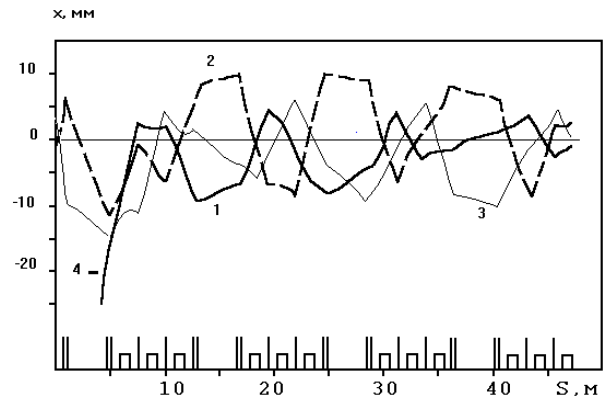


Fig.4. Trajectories of the injected beam in the first (1), second (2), third (3) turns, 4 - septum magnet knife.