BEAM OPTICS OF OPERATING MODES FOR DAMPING RING OF INJECTION COMPLEX VEPP-5

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Abstract

Damping storage ring (DR) is the part of Injection Complex which provides electron and positron beams for BINP collider experiments since 2015. Basic lattice parameters of the ring (optical functions, dispersions, betatron frequencies, etc.) of the operating modes are presented in the article. Actual calculations of the ring aperture limitations and energy acceptance after RF-system reconstruction are given. Some instruments for the beam orbit control and magnet system adjustment were developed and can be applied to improve the productivity of beams generation.

INTRODUCTION

Injection Complex VEPP-5 (IC) has been built in BINP, launched in 2015 and produces the intense relativistic beams of electrons and positrons for the needs of BINP colliders VEPP-4M and VEPP-2000.

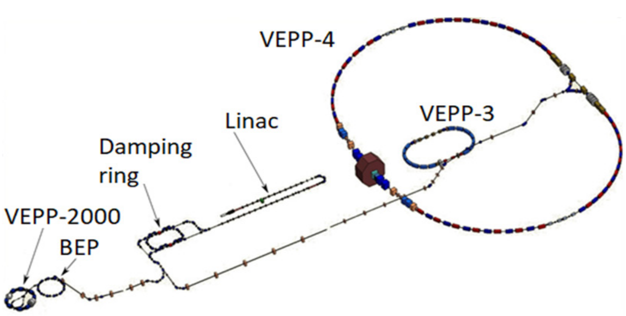

Figure 1: The system of BINP colliders.

Injection Complex includes Preinjector facility ("Linac" at Fig. 1) – the system of two linear accelerators and the conversion system for positron beams generation. Second machine as a part of IC is Damping ring - 27-meter synchrotron with quadrupole focusing. Preinjector and Damping ring are connected together with the couple of transport channels for electrons and positrons. Extraction channels system is used to deliver stored electron and positron beam to the colliders.

Damping Ring design is symmetric with two arcs with bending magnets and two straight sections between them (Figure 2). Electrons and positrons are injected to the ring at two different straight gaps and move in opposite directions. That allows to keep the ring magnet structure with unchanged magnet polarity and collect beams with different charge alternately.

Straight gaps are supposed to be non-dispersive to make it easier to match the injected beam parameters with the Damping ring acceptance.

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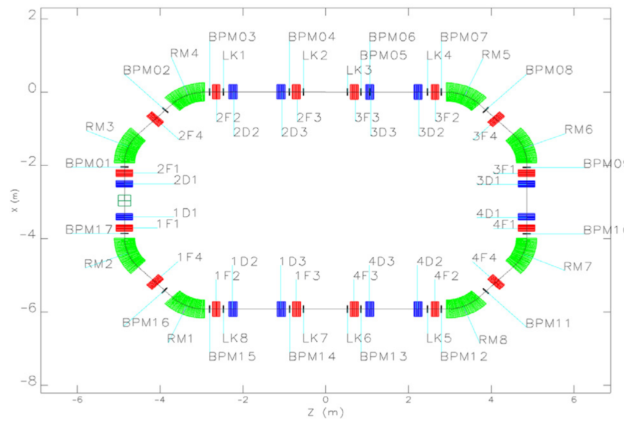

Figure 2: Damping Ring layout.

In order to inject new portions of particles to the stored beam in DR the following scheme is applied. The final parts of injection channels are in vertical plane. The final element of injection channel is vertical DC septum-magnet. It drives the newly injected beam to the horizontal trajectory which is parallel to the ring reference orbit. The stored beam is forekicked in horizontal plane closer to injected particles. When injected beam passes the septum, both bunches – stored and injected are kicked back to the ring orbit. Kickers are located in ¼ of betatron oscillation wavelength from the injection point to dump oscillations more effectively [1]. Residual transverse beam oscillations decay due to radiation damping.

DAMPING RING OPERATING PARAMETERS

Table 1: Damping Ring Parameters in 2017-2018

Beam Energy	395 MeV
Linac frequency	5 Hz
Electron storage rate	12.5 mA per cycle (6 shots) 7-10 mA/shot
Electron injection efficiency	30 %
Positron storage rate	12.5 mA per cycle (30 shots) 2.3 - 3 mA/sec
Positron injection efficiency	5.2 %
Betatron tunes positrons electrons	 νy=2.736, νx=4.645 νy=2.75, νx=4.635
Energy acceptance	+/- 0.025

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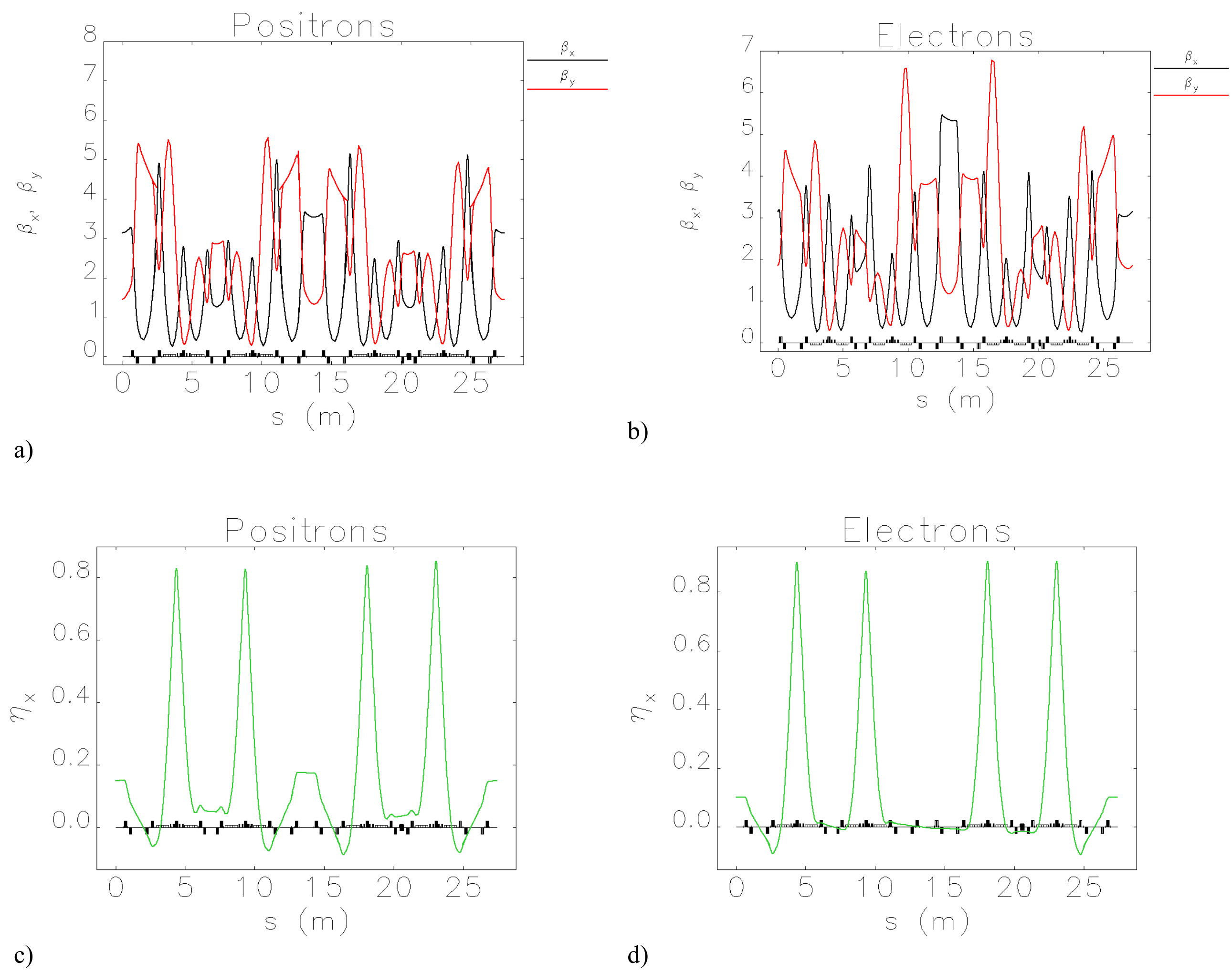

Figure 3: Optical and dispersion functions for Damping ring operation modes: a) positron beta-functions, b) electron beta-functions, c) dispersion of positrons, d) dispersion of electrons.

Damping Ring Modes

There are four different operating modes for IC: electron storage with following extraction to VEPP-2000 and VEPP-3 and same for positrons. To minimize the period of switches between modes it is desirable to keep as much as possible currents of magnet system unchanged. Practically during the operations and small orbit adjustments some differences arise.

Beam Optics

Electron and positron beta-functions and dispersion functions in the Damping ring are shown on Fig. 3a-3d. Magnet structure of the Damping ring was designed as symmetric, real lattice; then small differences were induced by the quadrupole corrections. Accurate geodesic data and ring magnet measurements were also applied for the optical model construction. Beam optics was calculated using “elegant” code [2].

Longitudinal Dynamics (Separatrix, Energy Acceptance)

Beam energy radiation losses are compensated by an accelerating RF cavity operating at a 10.96 MHz which is a frequency of beam revolution in the ring (ferrite resonator at a first harmonic is used). Particles with energy which is different from the reference value undergo the longitudinal oscillations. Energy change per turn can be described by the balance equation:

$$\Delta E_i = -eU_0 \sin\left(\frac{2\pi}{\Pi}\left(ct_{i-1} + \alpha_c \frac{\Delta E_{i-1}}{E_s} r\right) + \phi_s\right),$$

where α_c is the momentum compaction factor, U_0 is the resonator cavity voltage, E_s, ϕ_s are the energy and the phase of reference particle.

Phase trajectories for synchrotron oscillations are shown on Fig. 4.

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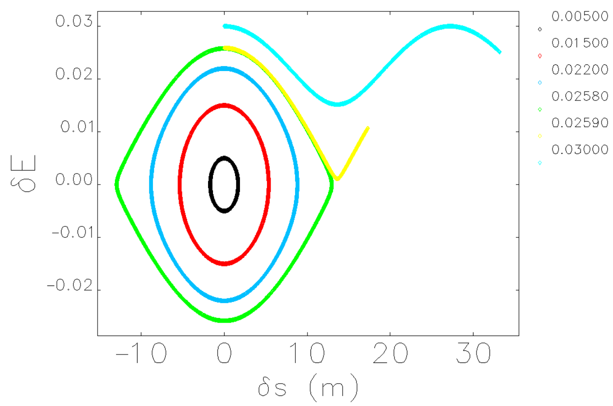
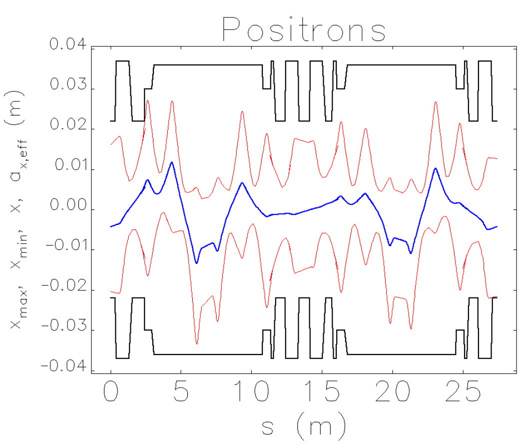


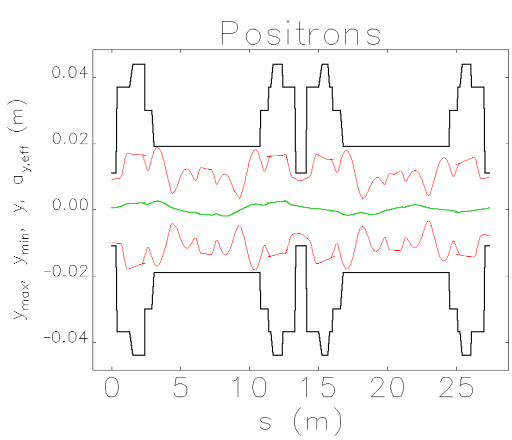
Figure 4: Phase trajectories for synchrotron oscillations.

Apertures

The studies of accessible by the beam mechanical apertures were also made.



a)



b)

Figure 5: Closed orbit and aperture limits for positrons. a) horizontal beam motion, b) vertical motion.

Black lines on Fig. 5 are the vacuum chamber borders. Red lines are the maximum (in absolute) values of particle coordinates at the area where beam motion is stable. These data can be used for broadening of accessible area for the beam and to avoid aperture losses.

Orbit Correction

At the start of new beam season in 2017 the beam orbit adjustments were performed without most of beam position monitors which were under upgrade. To control beam storage rates the damping ring current monitor was used that led to some closed orbit distortions (see above). At the start of new operation season in October 2018 the beam orbit correction works will precede the start of beam delivery to IC users.

The corrector-to-BPM response matrix gives the magnificient piece of information for both orbit control and optics analysis. Responses can be easily measured for x and y coordinates and betatron frequencies ν_x , ν_y.

The solution of linear equation for responses $R\Delta I = \Delta X$where

$$R_{ij} = \frac{\delta X_i}{\delta I_j} \text{or} R_{ij} = \frac{\delta \nu_i}{\delta I_j}$$

gives the massive of corrector current that can be used for the orbit correction.

At the new season of IC beam production the operation energy of Damping ring from 395 MeV to 420 MeV also can be planned. The particle beam with higher energy gain in linear accelerator has the lower energy spread gain. On the other hand the higher energy of extracted beam provides more effective use of the beam by IC facility users.

CONCLUSIONS

Electron and positron orbit parameters in Damping ring were reconstructed by matrix calculations and multi-particle tracking based on magnet measurements and geodesic element coordinate scanning. Beam optics and orbit for particles in the ring can be optimized and corrected when orbit measurements from the upgraded pick-up set are obtained.

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[2] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source LS-287, September 2000.