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CALCULATION OF INJECTION EFFICIENCY TO DAMPING RING OF VEPP-5 INJECTION COMPLEX

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Abstract

VEPP-5 Injection Complex (IC) is an electron and positron beam source for VEPP-4M and VEPP-2000 experimental facilities. IC consists of Preinjector - the system of two linear accelerators and conversion target, and Damping Ring where particle beams are collected before extraction to the users.

One of the factors that determine the performance of IC is the number of positrons which can be transported from Preinjector to Damping Ring and stored on the stable orbit. Estimations of the maximal efficiency of the beam generation include the beam loss calculations in the transport line between linear acceleraotrs and ring and analysis of the injected beam capture in the storage ring. Results of these calculations are presented in the report.

INTRODUCTION

Injection Complex VEPP-5 (IC) has been built in BINP, launched in 2015 and presently produces the intense relativistic beams of electrons and positrons for the needs of BINP colliders. Figure 1 demonstrates the main components of the complex.

Preinjector system (1 at Fig. 1) consists of two linear accelerators. At first the electron beam is generated, accelerated to 200 MeV and transported to the convertion system (2). If positrons are required to be stored, the electron beam is directed to the tantalum conversion target, positrons are collected from electromagnetic shower with the magnet flux concentrator [1] and transported along the second linear accelerator to the Damping Ring (Fig. 1, 3) and accelerated up to the ring operating energy (395 MeV in 2017-2018). In electron acceleration mode the electron beam bypasses the target and is also accelerated to the same operating energy value.

Damping Ring (DR) is 27-meter circular accelerator. DR can store both types of particles but not simultaneously. Most of the time Damping ring works with positrons since they are delivered to the machine in smaller quantities. When any type of particles is injected to the ring, new portions of particles are added to the circulated bunch until the required number of particles is stored. It is sufficient to store 3 pulses of electrons and 30 pulses for positrons at beam generation frequency 5 Hz. Synchrotron radiation losses are compensated by RF-cavity resonator that leads to a cooling down the transverse phase space of the beam.

Electrons and positrons are injected to the ring at two different straight gaps between arcs and move in opposite directions. Two different injection lines (4) connect Preinjector with the Ring. 3-degree vertical corrector located at the end of positron linear accelerator and drives positrons to the upper line and electrons to the lower one. Electron channel is straight in horizontal plane and contains the vertical chicane (so called "bridge") to pass by the arc of Damping Ring and inject beams to the non-dispersive straight gap. Opposite straight gap used for positron injection. The four-magnet horizontal achromatic parallel beam translation is used to drive positrons to the corresponding injection axis.

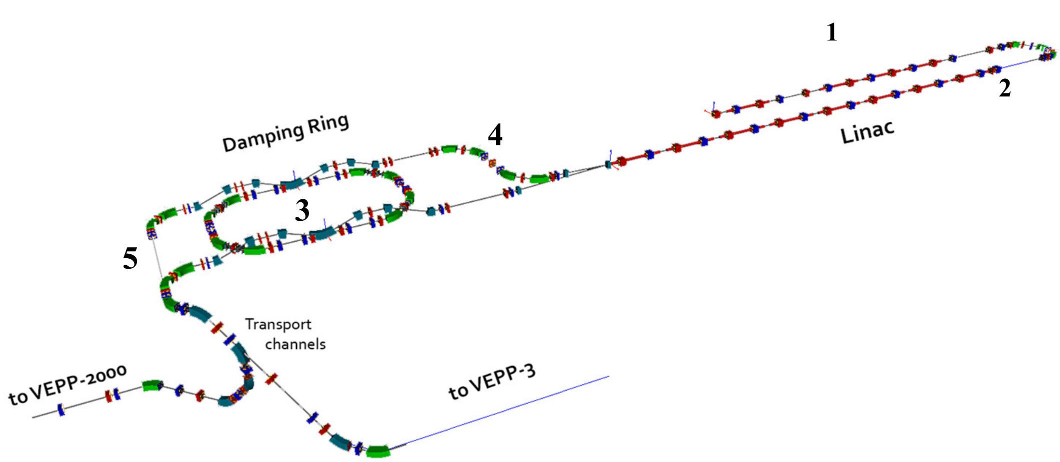

Figure 1: The layout of Injection Complex and extraction channels. 1 – Preinjector, 2 – conversion target, 3 – Damping Ring, 4 – injection channels, 5 – extraction channels.

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Stored and cooled beams of electrons and positrons are extracted from the DR by the system of transport channels (5) to the users' experimental facilities.

In 2017, the reconstruction of Damping Ring RF-system was performed. The new RF resonator operating at 1st harmonic of beam revolution frequency in the ring replaced the old resonator that was operating at 64th harmonic (see Table 1). Performed estimations [2] predicted the raise of particle injection efficiency at least 1.5-2 times since separatrix of the longitudinal oscillations is broadening.

Table 1: Damping Ring RF-system Parameters

	Frequency	Voltage
Old resonator	704 MHz	300 kV
New resonator	10.94 MHz	9.5 kV

The productivity of IC is determined by a positron storage rate. This article presents the results of numerical simulations of positron beam losses while they are transported from the conversion system to the Ring. The number of positrons that can be captured to the stable orbit in DR after injection was also calculated. The simulations were performed with the "elegant" code [3].

POSITRON BEAM IN PREINJECTOR

The quadrupole beam focusing is used at the most part of positron linear accelerator. However just after the convertor the energy of positron beam is low and the transverse scatter is too large so the additional solenoidal field is used in accelerator module to prevent loss of particle with large transverse momentum components. After acceleration in solenoid particles of the beam have energy up to 68 MeV and transverse scatter still appears to be a reason of beam losses.

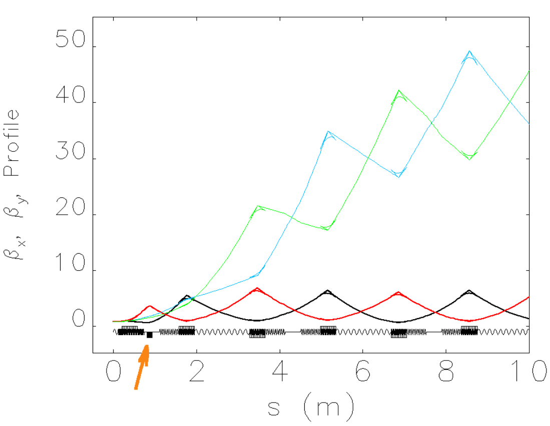

Figure 2: Beta-functions after solenoid in positron linear accelerator. Thick lines (red, black) – structure with additional quadrupole lens (indicated orange), thin lines (green, blue) – plain FODO structure.

Beam loss can be reduced partially if one adds one more quadrupole lens for better line optimization at the beginning of the regular FODO structure (see Fig. 2). That quadrupole was developed in BINP and installed on the accelerator after positron solenoid section.

For the successive betatron capture of beam to the circular machine the phase ellipse (which can be described in transverse plane with Twiss parameters β_x, α_x, β_y, α_y) and dispersion functions η_x, η_y at the end of injection channel must be adjusted with the similar functions of the ring at the injection point. Results of channel optimization are presented at Fig. 3-4.

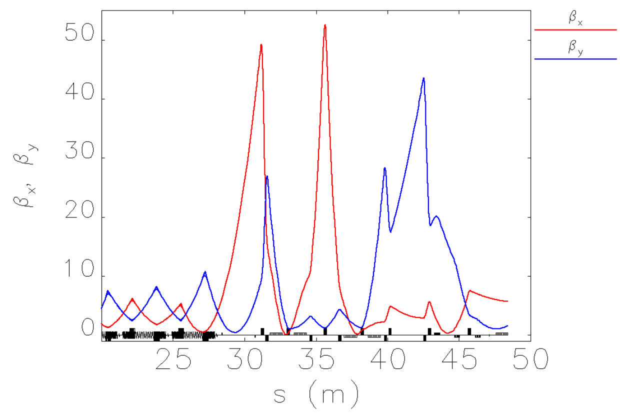

Figure 3: Beta-functions.

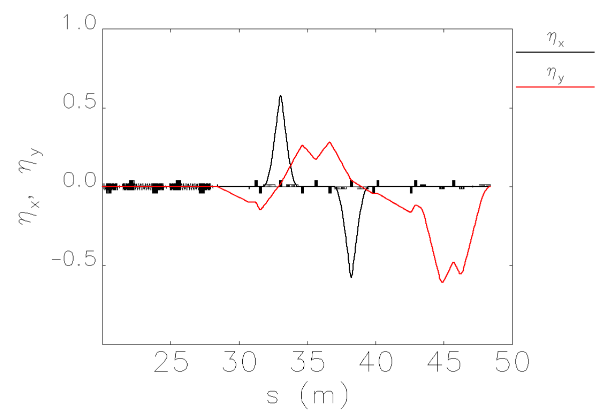

Figure 4: Dispersion functions.

"Elegant" was developed firstly for relativistic particle dynamics so the simulations of positron transport after conversion system, at magnet flux concentrator and positron solenoid were performed with GEANT code [1, 4].

4.6 10^9 positrons and 2 10^{10} electrons per pulse were registered by Faraday cup at the end of the positron accelerator during regular IC work. Further reduction of the positron beam loss directly after conversion system seems to require vast machine upgrade. So the ratio of the numbers of particles after the last acceleration structure and at the injection point in DR can be a figure of merit at current layout.

Figure 5 shows that about 31% of the particles can be transported through the adjusted positron injection channel. The most of the beam loss take place at the first

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vertical and horizontal magnets because of the limited energy acceptance in bends in compare with linear accelerator.

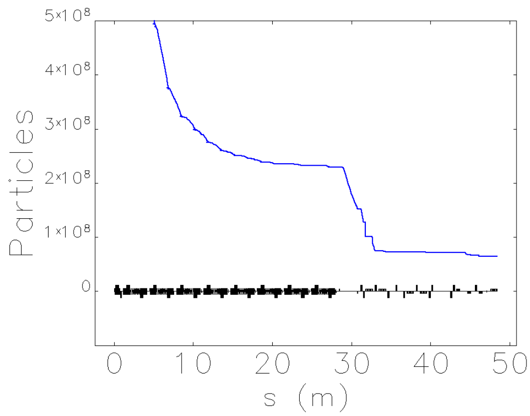

Figure 5: Beam loss in process of positron injection.

Damping Ring Energy Acceptance

One more restrictive factor for beam capture to the circular machine is its longitudinal beam dynamics. Energy change per turn can be described by the balance equation:

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

where α_c – momentum compaction factor, U_0 – resonator cavity voltage, E_s, ϕ_s – energy and phase of equilibrium particle.

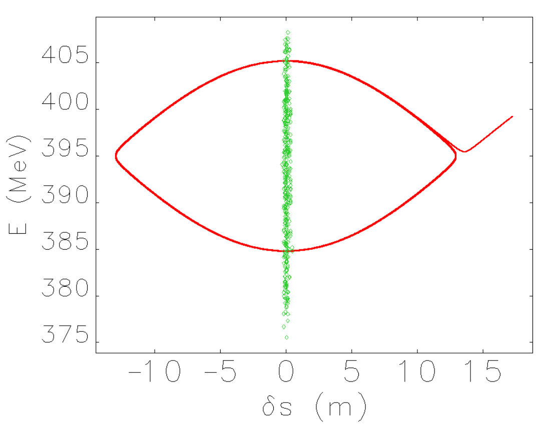

Figure 6: Damping Ring separatrix with injected beam.

Energy separatrix of the longitudinal oscillations with the injected beam portrait is shown on Fig. 6. For the modelled beam 77% of the particles that were transported to Damping Ring lay inside its separatrix. Considering that transport efficiency of positron injection channel is 31% one can obtain that 23% of number of positrons from the end of Preinjector finally were injected to DR and stored in it.

The same calculations for 700 MHz old resonator show 31% synchrotron capture of multi-bunched beam to the stable area of longitudinal oscillations (see Fig. 7) – and as a result 10% of particles from the end of Preinjector in the Ring. The new resonator should give injection improvement by 2-2.3 times.

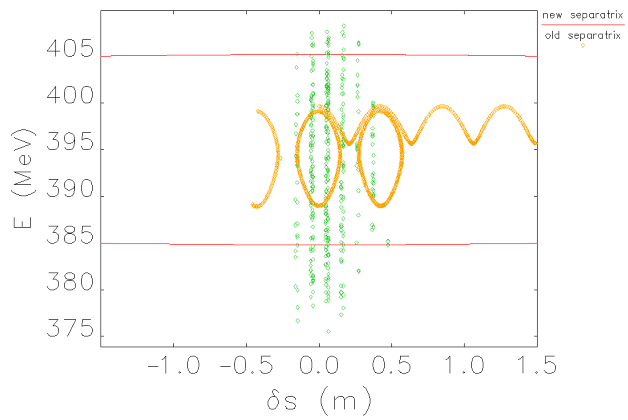

Figure 7: Injected beam in energy separatrix before and after RF-system upgrade.

CONCLUSIONS

Calculations and numerical tracking demonstrate that Damping ring resonator replacement provides 2-2.3 times increase for positron injection efficiency. For linacfrequency 5 Hz and 5 109 positrons at the end of Preinjector it is presumably possible to store up to 9.2 mA/sec in DR. Recent experiments showed positron storage rate as a 2.4 mAmper`/sec. This value possibly can be increased after some studies of positron closed orbit and geometric limits of aperture expanding.

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