VEPP-2000 ELECTRON-POSITRON COLLIDER COMMISSIONING

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Abstract

VEPP-2000 electron-positron collider construction has been completed in the Budker INP at the beginning of 2007 year. First beam was captured in a special lattice without final focus solenoids. In this regime all systems of power supplies, machine control and beam diagnostics were calibrated and tuned. In the same mode vacuum chamber treatment by synchrotron radiation was performed with electron beam current up to 150 mA.

The first test of the round beam option was performed at the energy of 508 MeV with the solenoidal field 10 T in two interaction straight sections. Studies of the beam-beam interaction have been done in "weak-strong" and "strong-strong" regimes. Measurements of beam sizes in the both cases have indicated a beam behavior similar to expectations for the round colliding beams.

INTRODUCTION

Budker Institute of Nuclear Physics has started the construction of the VEPP-2000 collider six years ago. At BINP for more than quarter of century the electron-positron collider VEPP-2M has been operated in the energy range of 0.4 ÷1.4 GeV. For a long time its results were the main source of information about hadrons production in this energy range. On the other hand, a whole number of events collected by different experimental groups in the energy span above VEPP-2M (up to 2 GeV) doesn't exceed 10 % of the data accumulated by VEPP-2M. These motivations caused a decision to create instead of VEPP-2M collider a new machine with higher luminosity (up to 10^{32}cm^{-2}s^{-1}) and the beam energy up to 2×1 GeV. For that, it's assumed to construct the new collider in the same experimental hall and use at least at the first stage the existing infrastructure of the accelerators and detectors.

To achieve the final goals (luminosity and energy) under such boundary conditions, the Round Beam Concept was applied in design of the machine optics [1]. The main feature of this concept is rotational symmetry of the kick from the round opposite beam. This is complemented by the $x-z$ symmetry of the betatron transfer matrix between the collisions. Together, it results in particle's angular momentum conservation ($M = xz' - zx' = const$). As a consequence, it yields an enhancement of dynamical stability, even with nonlinear effects from the beam-beam force taken into account.

Computer simulations of the beam-beam interaction in "weak-strong" and "strong-strong" situations confirmed these expectations [2-3].

VEPP-2000 MAGNET STRUCTURE

Magnetic focusing structure of VEPP-2000 [4] has the 2-fold symmetry. It includes two (3 m long) experimental straight sections, two straights (2.5 m) for beams injection and RF cavity and 4 short technical straights with 4 triplets of quadrupole magnets.

The RBC at VEPP-2000 was implemented by placing in the two Interaction Regions symmetrically with respect to collision points two pairs of superconducting solenoids.

The strong solenoid focusing provides equal beta-functions of the horizontal and vertical betatron oscillations. There are two combinations of solenoid polarities $(+ +\ \ + +)$ and $(+ +\ \ - -)$, that rotate the betatron oscillation plane by ± 90 degrees and give alternating horizontal orientation of the normal betatron modes. It results in equal tunes and equal radiation emittances of the betatron oscillations. But the simplest case $(+ -\ \ + -)$ with an additional small decompensation of solenoid fields also gives round colliding beams and satisfies the RBC requirements.

Superconducting Solenoids

Each solenoid is designed in two sections: main 13 T solenoid 50 cm in length, and 10 cm anti-solenoid (8 T). In part, the main solenoid consist of two identical units each of these has an inner coil wound with Nb$_3$Sn wire and an outer coil wound with NbTi wire. To feed the solenoid, we use separate power supplies for the outer and inner coils and for the anti-solenoid. All coils are embedded in the iron yoke located in a common LHe cryostat. At this stage the solenoids have been tested in an immersion cryostat and tested. After few quenches the required magnetic field 13 T was achieved.

Dipole Magnets

To achieve the designed energy of 1 GeV in the constrained VEPP-2M complex area, the magnetic field in the bending magnets of 2.4 T is required. An optimization of configuration and dimensions of the coils and the iron core yields this field level with a 10^{-3} non-uniformity in a 4×4 cm^2 gap. A power consumption per one 45 degree dipole magnet amounts to 60 kW. A special rectifier with 10 kA current and total power 1.5 MW has been developed.

Quadrupole, Sextupole, and Steering Magnets

The machine lattice includes 5 families of quadrupole magnets (max. gradient 50 T/m). Each family consists of 4 quads and has a common power supply with the current up to 300 A. The total power consumption is within 60 kW. The chromaticity of solenoid and quadrupole focusing is corrected by two families of sextupoles located in the technical straight section, in between the triplet sections, where the dispersion is high. To widen the dynamic aperture ($\geq 15\ \sigma_{x,z}$), the third sextupole family is applied in the injection and RF cavity straight sections. The closed orbit steering and gradient correction are done with 1-2% correction coils placed in the dipole and quadrupole magnets. current 2×150 mA.

BEAMS INJECTION

Electrons and positrons are injected (in turn) from the booster storage ring BEP with the maximum energy of 900 MeV[5]. The one-turn injection is done horizontally in the median plane of the ring. After a pulsed septum magnet the injected beam is focused while passing a quadrupole doublet and then kicked by a short pulse of a counter-propagating wave of a kicker plate. Two such plates are located along the inner side of the vacuum chambers in the two bending magnets adjacent to the injection drift and serve alternating as the kicker and pre-kicker by the injection of electrons or positrons. The kicker (pre-kicker) is supplied by SOS-diode generators, which produce 70 kV and 10 ns pulses.

Together with the adopted optics of the transfer line, this injection scheme gives a high injection efficiency with either combination of the SC solenoids polarities. This gives us an opportunity to test different variants of round colliding beams, and to have conventional flat colliding beams as well.

VACUUM SYSTEM

High vacuum pumping of the experimental straight sections is performed by an internal wall of the LHe vessel housing the SC solenoids. In other places combined ion-pumping and getter pumping are used to cope with gas desorption from the vacuum pipe irradiated by the synchrotron radiation. Bakeable stainless steal vacuum chamber is equipped with water-cooled radiation cooper absorbers and have to provide vacuum 10^{-6} Pa at the beam current 2×150 mA.

BEAM DIAGNOSTIC

Each vacuum chamber contains (in the middle cross section) a water cooled triangle mirror, which reflects the visible part of the synchrotron radiation from both beams. This light goes outside through a glass window to the optical diagnostic system: beam current (PMT) and beam position and dimensions measurements. CCD-cameras are used as beam position and size recorders in 16 points around the ring. In addition to optical BPMs there are 4 pick-ups in the technical straight section and one current transformer as an absolute current monitor.

RF SYSTEM

The accelerating RF cavity is placed in the drift opposite to the injection straight [6]. It operates on the 14-th revolution frequency harmonic (172.0 MHz.). The accelerating voltage of 100 kV provides a bunch length about 3 cm at the energy of 1 GeV. Energy loss for the synchrotron radiation is 50 keV per turn on the top energy. RF power delivered to the beams equals to 10 kW with colliding beams currents 2×0.1 A The so-called single mode cavity is applied, aiming a stable operation with intense bunches. A HOM damping scheme of the cavity uses two different HOM loads, one is a waveguide load and other is a coaxial load. These HOM modes are being trapped by waveguide load or are being damped in another load.

FIRST BEAM

Before commissioning of VEPP-2000 itself we had to restore the injection part of the accelerator complex. This work started in the early 2006 and was developed step by step following a readiness of corresponding control and supply systems along a chain of transfer lines and accelerators: 3 MeV linac ILU, 250 MeV synchrotron B-3M, buster storage ring BEP. This process reached the VEPP-2000 border near to the end of year.

At the first stage the optics of VEPP-2000 was simplified to the conventional option without solenoids. This "soft" optics ($\nu_z = 1.2;\ \ \nu_x = 2.4$) is quite different from the round beam lattice. But a part of the lattice near injection is similar to the project one. The first circulating electron beam was caught at the energy of 140 MeV and soon after at 508 MeV. At the energy of 508 MeV, which was limited at that time by the bending magnets power supply, the whole computer control, beam diagnostic, and steering coils have been tested, tuned and calibrated.

ROUND BEAM

When the beam efficiency transfer achieved 70-80 %, the vacuum chamber treatment by the synchrotron radiation was done with electron beam in both directions. Beam current, while few days training, raised up to 150 mA and the beam lifetime achieved 1000 sec. At that condition, the lifetime of low beam current (about 1mA) exceeds 10 hours.

To start the round beam operation, first of all, we had to align the cooled solenoids. It was done in the same "weak focusing" regime by the CO deviation measurements as a response to the orbit steering coils. Each section of all 4 solenoids has been tested with magnetic field level up to 4 T. So, coordinates of each i-th solenoid section center (x_i, z_i, x_i', z_i') have been obtained from the Orbit Response Matrix analysis (ORM), and necessary mechanical adjustments of the solenoids have been done. After this preliminary alignment the simplest round beam regime ($+-\quad +-$) was applied with 1 T field in the anti-solenoid and 10 T in the nearest to IP section of the main solenoid. The round beam machine lattice for $\beta^* = 4.5\ \text{cm}$ is shown in Fig. 1.

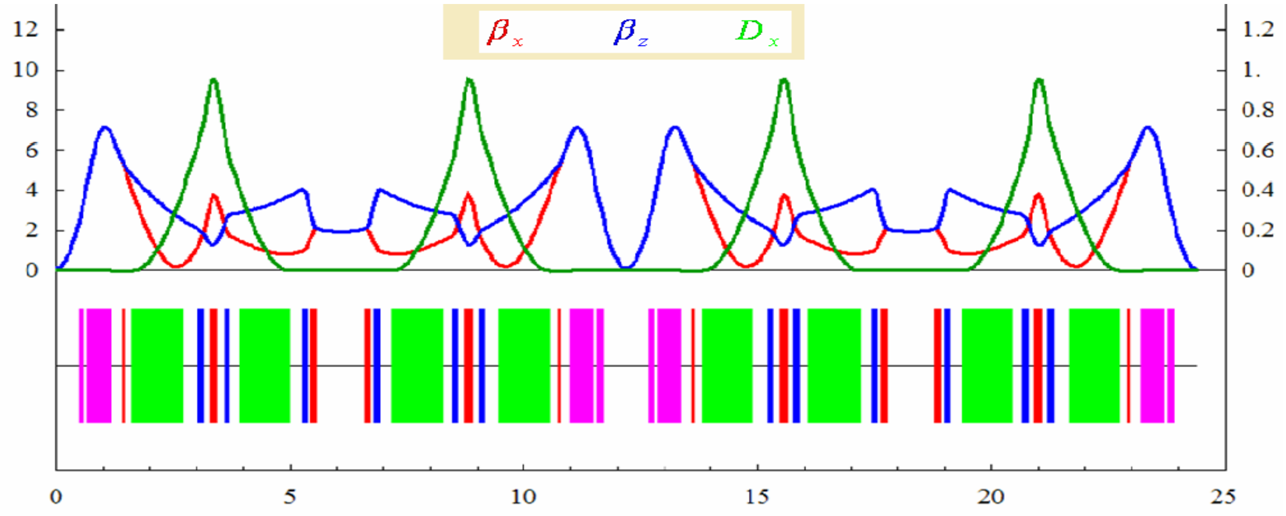

Figure 1: VEPP-2000 lattice (solenoids "on")

The electron beam was successfully injected just after the solenoids "on", with fractional tunes near a half-integer, $\Delta\nu_1 \approx \Delta\nu_2 \approx 0.5$. Later on, few steps of the CO and lattice functions corrections have been done aiming to bring the tunes near to integer. At that, the SVD method was routinely used to minimize a sum of currents in dipole steering coils and deviations in focusing strength of quadrupoles and solenoids from original symmetry. Finally, we get a regime with $\Delta\nu_1 \approx \Delta\nu_2 \approx 0.1 \div 0.15$ and moderate CO deviations ($\Delta x \approx \Delta z \le \pm 1.5\,mm$) from the axes of quadrupole magnet.

Experimentally we measured horizontal and vertical beam dimensions of the positron beam in other positions. The Fig. 2 presents rms beam dimentions (I^+=3 mA) at three points versus the electron beam current. In point 3 located in the dipole nearest to IP, there is a minimum of β_x (see the Fig. 1). The horizontal rms size behavior at this point.

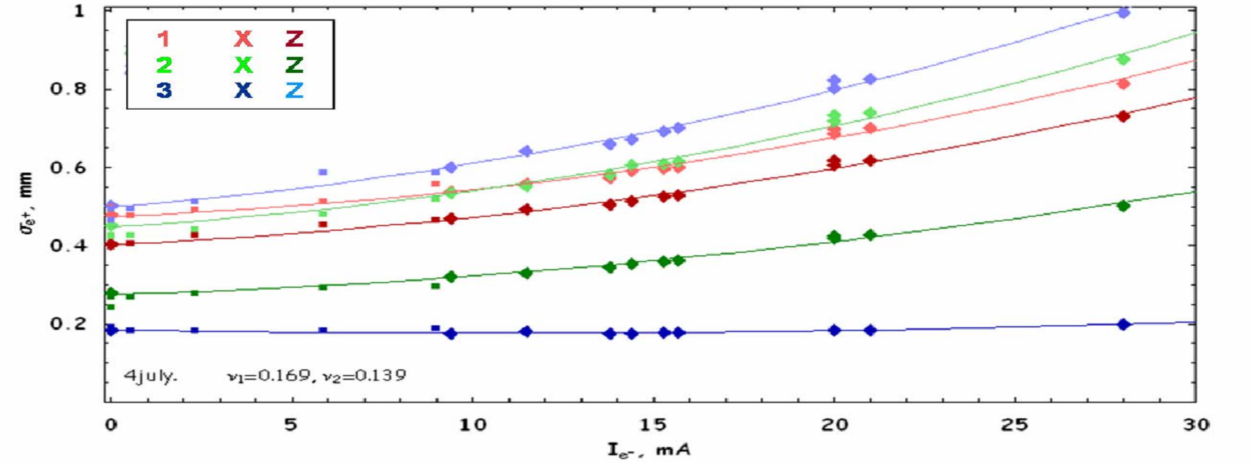

Figure 2: Positron beam rms sizes versus electron current

ROUND COLLIDING BEAM TEST

For the beginning we have studied the round colliding beams in the "weak-strong" option. The simulation of the "weak-strong" option predicts a weak dependence of the IP beam size σ_0 on the opposite beam strength. has to be similar to the IP. One can remark, that $\sigma_x(3)$ (dark blue curve) does not change in accordance with the simulation. The vertical size (light blue) grows as a result of the counter beam focusing, which increases the radiation emittance and β_z in the point 3. Such beam behavior was observed up to electron beam current I^-=50 mA, that corresponds to the space charge parameter $\xi = \frac{N r_e \beta^*}{4\pi\gamma\sigma_0^2}$ 0.1

After "weak-strong" option study we have increased both beam current and relatively easy have got a luminosity value $L = 1\times10^{31}cm^{-2}s^{-1}$, that exceeds in few times the luminosity record of VEPP-2M on the same energy. More demonstrative advantages of the round beam option are presented in the Fig.3, where the specific luminosities are shown versus the electron beam current for flat beams (black points - VEPP-2M data [7]) and for round beams (red curve).

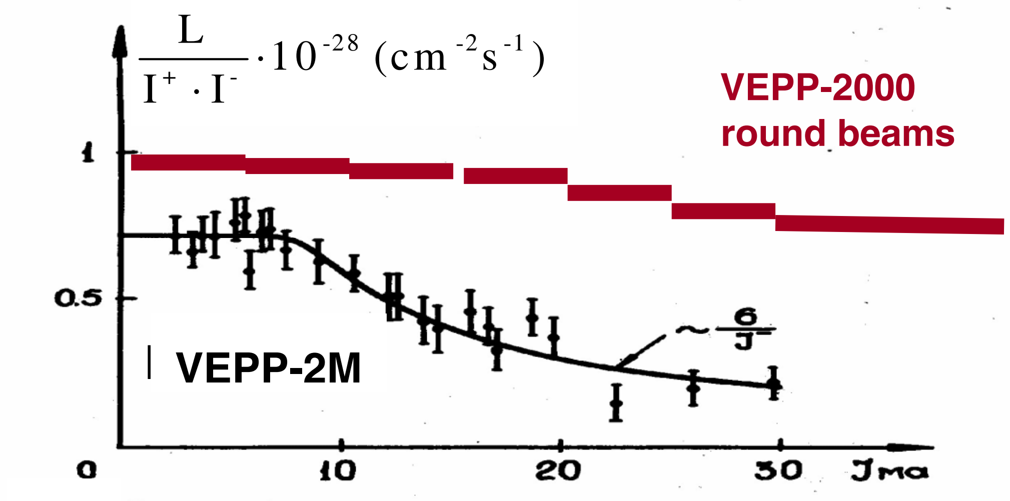

Figure 3: Specific luminosities versus electron current

CONCLUSION

The VEPP-2000 commissioning have been successfully carried out during 2007 year. Beam diagnostics calibration and vacuum conditioning have been done in the special optics without solenoids. The same regime was used for the solenoids alignment using CO offsets in recoils on each solenoid excitation.

The experimental results of the beam-beam study in the round beams mode have confirmed our expectations for the beam size behaviour in the "weak-strong" and "strong-strong" situations. In the "weak-strong" case the electron current achieves the value I^-=50 mA. It corresponds to the space charge parameter value $\xi = 0.1$ The record luminosity $L = 1\times10^{31} cm^{-2}s^{-1}$ has been achieved by the value $\xi \approx 0.08$ with beam currents $I^+ \times I^- = 35\times45\ (mA)^2$ and the life time $\tau \approx 1000\,s$. These numbers are dependent on a residual coupling and the tunes working point. We are planning to proceed with the beam-beam studies in the next run.

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