Письма в ЭЧАЯ. 2008. Т. 5, № 7(149). С. 41–48

ФИЗИКА И ТЕХНИКА УСКОРИТЕЛЕЙ

VEPP-2000 COLLIDER COMMISSIONING[1]

Yu. M. Shatunov (for VEPP-2000 Team)

Budker Institute of Nuclear Physics, Novosibirsk, Russia

VEPP-2000 construction has been completed at the end of 2006. First beam was captured in a special regime without final focus solenoids. In this regime all systems of power supplies and machine control 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.

В конце 2006 г. в ИЯФ СО РАН было закончено сооружение нового электрон-позитронного коллайдера ВЭПП-2000. Первый пучок электронов был получен в специальном «техническом» режиме без включения сильных соленоидов в экспериментальных промежутках. В этом режиме все системы питания и управления комплексом, а также устройства диагностики параметров пучка были настроены и откалиброваны. Испытание вакуумной камеры накопителя синхротронным излучением было проведено электронным пучком с током до 150 мА в том же режиме. Первые измерения эффектов встречи, проведенные при энергии 508 МэВ с магнитным полем соленоидов 10 Тл, показали значительно большую устойчивость «круглых пучков» по сравнению с обычными плоскими пучками.

PACS: 29.20.-c

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) does not 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} $\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}$) and the beam energy up to 2×1 GeV. For that, it is 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.

[1]Construction of VEPP-2000 was supported by the ISTC grant 1928.

Together, it results in particle's angular momentum conservation ($M = xz' - zx' = \mathrm{const}$). As a consequence, it yields 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].

The RBC at VEPP-2000 was implemented by placing symmetrically with respect to the collision points two pairs of 13 T superconducting solenoids in the two interaction regions equipped with particle detectors (see Fig. 1).

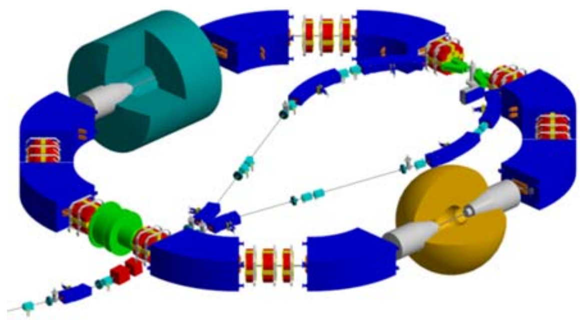

Fig. 1. Layout of VEPP-2000 collider scheme

The strong solenoid focusing provides equal (and small) beta-functions of the horizontal and vertical betatron oscillations. There are three combinations of the solenoid polarities $(++\ \ ++)$, $(++\ \ --)$, $(++\ \ +-)$, when each solenoid pair rotating the betatron oscillation plane by $\pm 90°$, gives alternating horizontal orientation of the oscillation normal 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.

LAYOUT OF VEPP-2000

The general layout of VEPP-2000 collider is shown in Fig. 1. It is 2-fold symmetry ring with two experimental straight sections (3 m long), two straights (2.5 m) for beams injection and RF cavity and 4 short technical straights with 4 triplets of quadrupole magnets.

BEAMS INJECTION [4]

Electrons and positrons are injected (in turn) from the booster storage ring BEP with the maximum energy of 900 MeV [4]. 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.

MAGNET SYSTEM [5]

Dipole Magnets. To achieve the beam energy of 1 GeV in a constrained VEPP-2M complex area, the field of 2.4 T is required in the bending magnets. 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 gap. The power consumption amounts to 60 kW per a $45°$ dipole magnet. A special rectifier with 10 kA current and total power 1.5 MW has been developed.

Superconducting Solenoids. To provide tunable focusing and 90° rotation of the oscillation planes, each solenoid is designed in two sections: main 13 T solenoid 40 cm in length, and 8 T anti-solenoid 10 cm in length. In part, the main solenoid consists of two identical units, each of these has the inner coil wound with Nb_3Sn wire and the outer coil wound with NbTi wire. To feed the solenoid, we use separate power supply units 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. After few quenches the required magnetic field 13 T was achieved.

Then, a final assembling with vacuum vessel and LHe tank was done. Tests of solenoids installed at the storage ring showed a liquid helium consumption twice higher than a calculated one (Fig. 2).

The internal tube of the helium vessel (50 mm in diameter) is a part of the collider vacuum chamber and thus provides for cryogenic pumping in the interaction straight sections. The synchrotron radiation from the bending magnets is intercepted by a nitrogen vapor-cooled liner placed inside.

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 ($\geqslant 15\sigma_{x,z}$), 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.

RF SYSTEM [6]

The accelerating RF cavity (see Fig. 3) is placed in the drift opposite to the injection drift. It operates at the 14th revolution frequency harmonic (172 MHz). With the accelerating voltage of 100 kV the bunch length is about 3 cm at the energy of 1 GeV. Energy loss for the synchrotron radiation is 50 keV per turn at the maximum energy, and with colliding beams currents 2×0.1 A the power delivered to the beams equals to 10 kW. The so-called

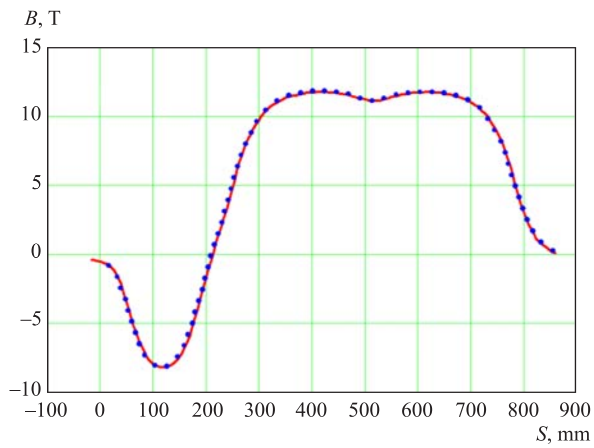

Fig. 2. Longitudinal field in solenoid

single-mode cavity is installed, aiming at stable operation with intense bunches. A HOM damping scheme of the cavity uses two different HOM loads, one is a waveguide load and the other is a coaxial load. Those HOM modes which are being trapped for one load usually are being damped in another load.

VACUUM SYSTEM

High vacuum pumping of the experimental straight sections is performed by the internal tube of the LHe vessel housing the SC solenoids. In the rest regions, 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 should provide vacuum 10^{-6} Pa at the beam current 2×150 mA.

BEAM DIAGNOSTICS

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 (see Fig. 5 below). In addition to optical BPMs there are 4 pick-ups in the technical straight section and one current transformer as an absolute current monitor.

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

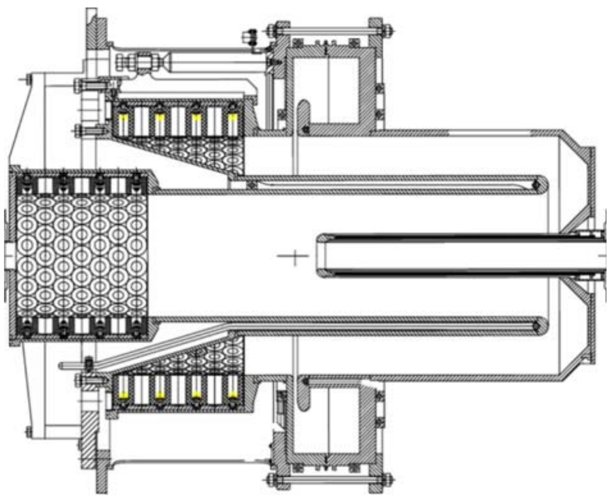

Fig. 3. Cross section of VEPP-2000 cavity

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 the year.

At this stage the optics of VEPP-2000 was simplified to the conventional option without solenoids (see Fig. 4).

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 diagnostics, and steering coils have been tested, tuned and calibrated.

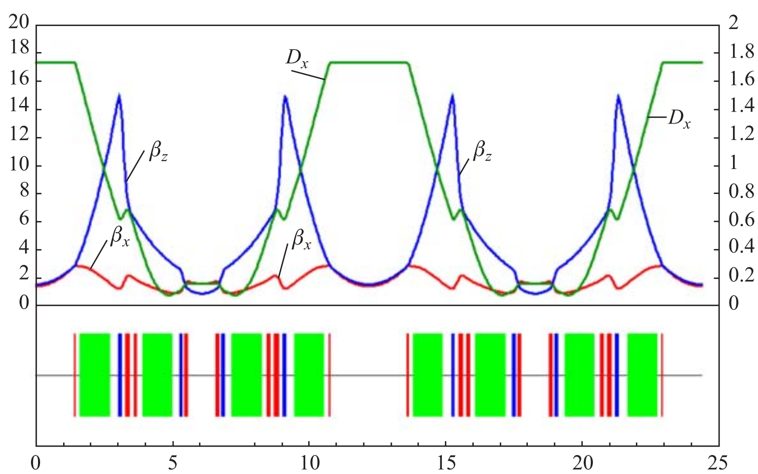

Fig. 4. VEPP-2000 lattice (solenoids «off»)

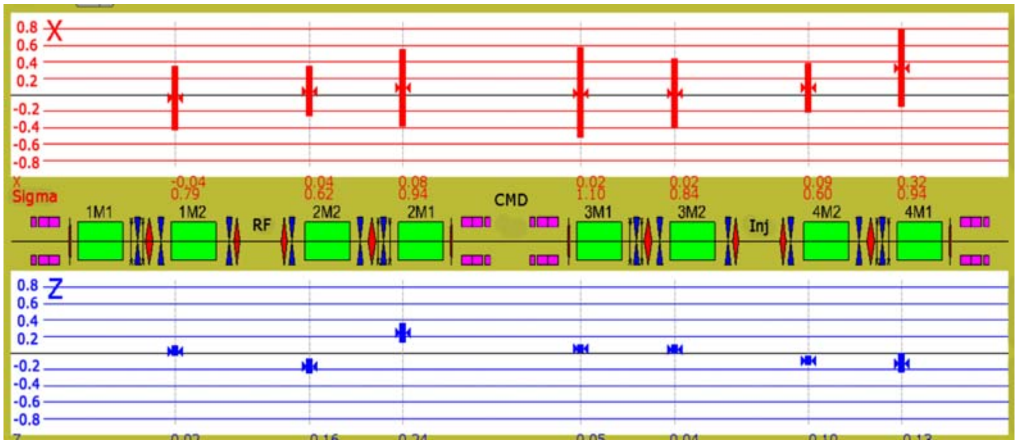

Fig. 5. Picture from monitor of the beam sizes and coordinates taken by CCD

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 s. At that condition, the lifetime of low beam current (about 1 mA) exceeds 10 h.

ROUND BEAM

VEPP-2000 operation without solenoids took about half a year. It was caused mainly by a low capacity of the liquid helium production at BINP, which was not enough to keep simultaneous experiments at VEPP-4M collider and solenoids feeding at VEPP-2000. Only at the end of May 2007 the cryogenic system of VEPP-2000 was put into operation.

First of all, we had to prove an alignment of the cooled solenoids. It was done by the CO deviation measurements as a response to the orbit steering coils, first performed in the same «weak focusing» regime. Each section of all 4 solenoids was tested with magnetic field

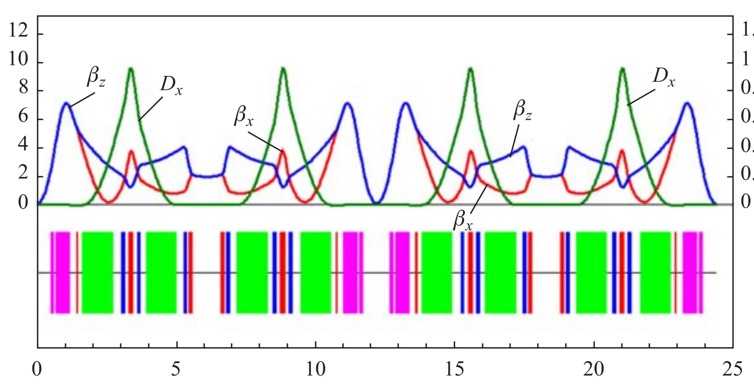

Fig. 6. VEPP-2000 lattice (solenoids «on»)

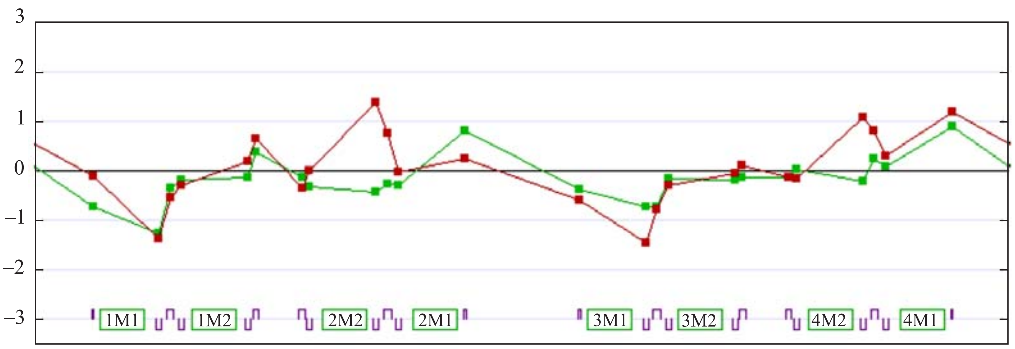

Fig. 7. Beam closed orbit in focusing elements after SVD processing

level up to 4 T. So, coordinates of each ith solenoid section center (x_i, z_i, x'_i, z'_i) have been obtained from the Orbit Response Matrix analysis (ORM), and necessary mechanical shifts of the solenoids have been done. After this preliminary alignment the simplest round beam regime ($+-\ \ +-$) 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 $\beta^* = 4.5$ cm is shown in Fig. 6.

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 $\Delta\nu_1 \approx \Delta\nu_2 \approx 0.1{-}0.15$ and moderate CO deviations ($\Delta x \approx \Delta z \leqslant \pm 1.5$ mm) from the axes of quadrupole magnets (see Fig. 7).

ROUND COLLIDING BEAMS TEST

At that time one system of the storage ring was not complete. Instead of four kicker generators, only two of them were in operation. So, we could inject the beams, but without storage. Also the positron source worked far from its full strength. It was able to deliver the positron current of 3–4 mA only in the VEPP-2000. In this situation we came to a decision to make a round colliding beam test in the «weak–strong» option rather than curing some visible machine imperfections. The simulation of the «weak–strong» option predicts a weak dependence of the IP beam size on the opposite beam strength ξ (see Fig. 8).

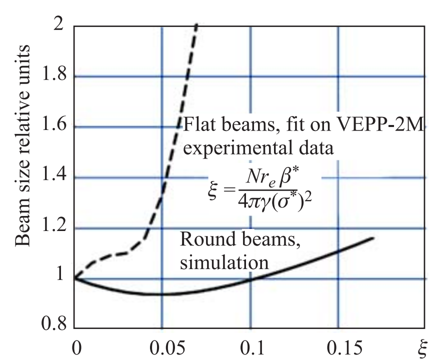

Fig. 8. «Weak–strong» simulation

Experimentally we measured horizontal and vertical beam dimensions of the positrons in other positions. Figure 9 presents the rms beam sizes at three points vs the electron beam current. In point 3 located in dipole nearest to IP, there is a minimum of β_x seen in Fig. 6.

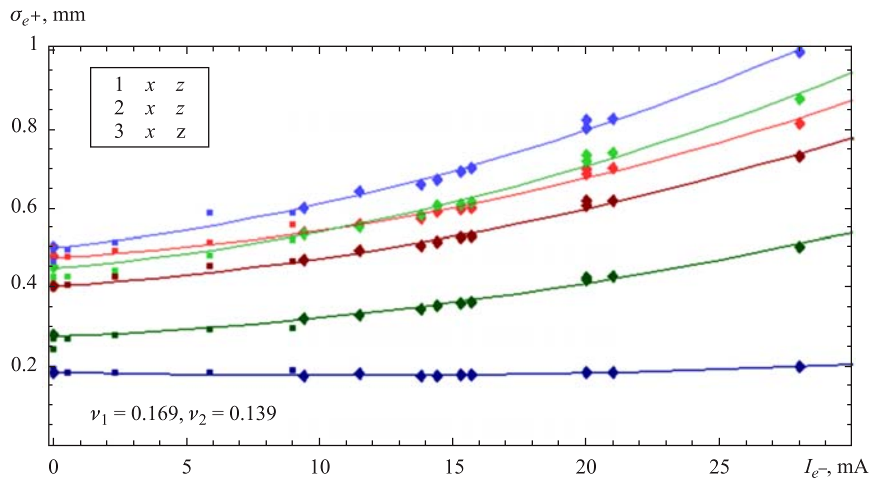

Fig. 9. Positron beam rms sizes vs electron current

According to the simulation, the horizontal rms size behaviour at this point (dark) is similar to IP. The vertical size (light) grows as a result of the counter beam focusing, that increases β_z and the radiation emittance.

CONCLUSION

From the experimental data of the «weak–strong» beam–beam interaction we can conclude that the behaviour of the weak beam is more or less in accordance with the expectation taking into account mentioned above machine imperfections. In Fig. 9 the electron current achieved 30 mA. It corresponds to the space charge parameter value $\xi \simeq 0.06$. At that value, the positron beam lifetime degradation was not too strong. A critical value $\xi \approx 0.08$ appeared at the electron current 38 mA with a dramatic drop in the beam lifetime, $\tau \leqslant 100$ s. These numbers are dependent on the residual coupling and the tunes working point. We are planning to proceed with the beam–beam studies in the next run while waiting for completion of detectors assembling.

REFERENCES

1. *Danilov V. V. et al.* // Proc. of the EPAC. V. 2. Sitges, 1996. P. 1149.
2. *Shatunov Yu. M. et al.* // Proc. of the EPAC. Vienna, 2000. P. 439.
3. *Valishev A. A. et al.* // Proc. of the PAC. Oregon, 2003. P. 3398.
4. *Berkaev D. E. et al.* // Proc. of the EPAC. Edinburg, 2006. P. 622.
5. *Berkaev D. E. et al.* // Ibid. P. 628.
6. *Arbuzov V. S. et al.* // Proc. of Rus. PAC. Dubna, 2004. P. 324.