STATUS OF THE VEPP-2000 COLLIDER PROJECT

Yu.M. Shatunov for the VEPP-2000 Team
Budker Institute of Nuclear Physics, 630090, Novosibirsk, Russia

Abstract

The VEPP-2000 collider which is now under construction in the Budker Institute will operate with round colliding beams at the energy of up to 1 GeV per beam. In this paper the current status of manufacturing, assembling and testing is reviewed. Results of beam-beam simulation for round beams are given.

INTRODUCTION

A decision to upgrade the VEPP-2M complex by replacing the existing collider with a new one in order to improve the luminosity and at the same time increase the maximum attainable energy up to 2 GeV will significantly broaden the potential of experiments performed at the collider. The new project was given the name "VEPP-2000" based on the center-of-mass energy and year when the project has been approved.

Figure 1 shows the layout of the VEPP-2000 complex. It consists of 2.5 MeV linac, 250 MeV synchrotron, booster ring and the VEPP-2000 storage ring. The booster can change polarity to store subsequently electrons and positrons and is capable of accelerating beams up to the energy of 900 MeV. Above this level the energy of the collider will be ramped to the energy of experiment. The injector is kept unchanged from the VEPP-2M collider except the power supply and control systems.

The design luminosity of VEPP-2000 at 1 GeV is $1\times10^{32} cm^{-2}s^{-1}$.

ROUND COLLIDING BEAMS CONCEPT

The basic parameter of a collider is its luminosity L which in the case of short bunches is determined by the formula:

$$L = \frac{\pi\gamma^2 \xi_y \xi_x \varepsilon_x f}{r_e^2 \beta_y} \cdot \left(1+\frac{\sigma_y}{\sigma_x}\right)^2,$$

where ξ_y, ξ_x are the space charge parameters whose maximum values are limited by beam-beam effects; ε_x is the horizontal emittance of the beams, σ_y, σ_x are their r.m.s. sizes at the interaction point (IP), and β_y is the vertical beta-function at the IP; f is the frequency of collisions at this IP, r_e is the classical electron radius, γ is the relativistic factor.

The space charge parameter per interaction is:

$$\xi_{x,y} = \frac{Nr_e}{2\pi\gamma} \cdot \frac{\beta_{x,y}}{\sigma_{x,y}\left(\sigma_x+\sigma_y\right)},$$

where N is the number of particles in the opposite bunch. Colliding bunches with maximum values of $\xi_y \approx 0.05$ and $\xi_x \approx 0.02$ have been experimentally obtained at the VEPP-2M collider [1].

Aiming at a very high luminosity due to raising the ξ limits in the Novosibirsk Φ-factory project [2,3], colliding beams with round transverse cross-sections were proposed (just "round beams" in what follows). During the last decade at BINP, this approach evolved into the concept of Round Colliding Beams (RCB) [4].

In the RCB case, the luminosity formula has the form:

$$L = \frac{4\pi\gamma^2\xi^2\varepsilon f}{r_e^2\beta},$$

and the space charge parameters are now the same in the two directions, so the horizontal parameter can be strongly enhanced.

The evident advantage of round colliding beams is that with the fixed particle density, the tune shift from the opposite bunch becomes twice as small as the tune shift in the case of flat colliding beams. Besides, the linear beam-beam tuneshift in the round beams becomes independent of the longitudinal position in the bunch, thereby weakening the action of synchrobetatron resonances.

The main feature of the RCB is rotational symmetry of the kick from the round opposite beam; complemented with the $X-Y$ symmetry of the betatron transfer matrix between the collisions, it results in an additional integral of motion $M = xy' - yx'$, i.e. the longitudinal component of particle's angular momentum is conserved. Thus, the transverse motion becomes equivalent to a one-dimensional (1D) motion. Resulting elimination of all nonlinear betatron coupling resonances is of crucial importance, since they are believed to cause the beam lifetime degradation and blow-up.

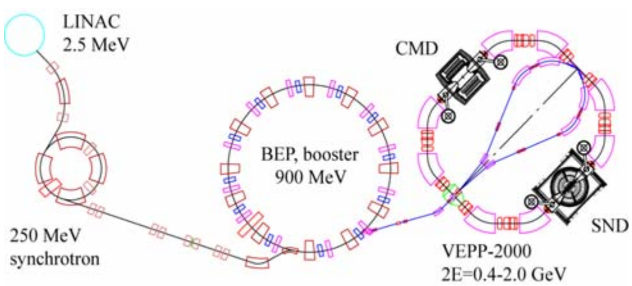

Figure 1. Layout of the VEPP-2000 complex.

LATTICE OF VEPP-2000

The round beam optics for a collider with small energy and two interaction points can be practically realized using solenoids as the main focusing elements in experimental straights. In this case the lattice consists of two symmetrical achromatic arcs with conventional optics, and solenoidal blocks on both sides of the IPs (Fig. 2). Besides the focusing, each solenoid rotates the plane of betatron oscillations by $\pi/4$. By switching the polarity of the blocks one can arrange various options:

- *conventional flat beam*, when the rotation over the IP is zero.
- *round beam*, when rotation over one turn is zero, but the x-y modes interchange between the arcs
- "mobius" ring with one-turn rotation equal to π.

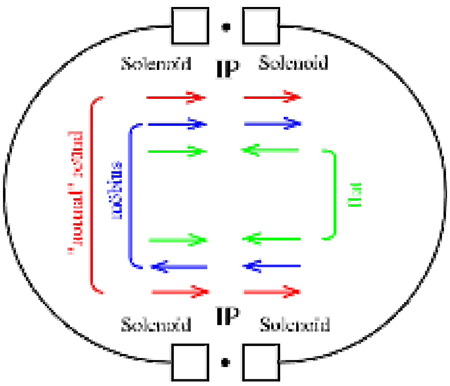

Figure 2. Practical realization of round beams.

For the main operation mode with round beam the following conditions are fulfilled:

$$Q_x = Q_y, \quad \varepsilon_x = \varepsilon_y, \quad \beta_x^* = \beta_y^*.$$

The optical functions of the round beam lattice of VEPP-2000 are presented in Figure 3.

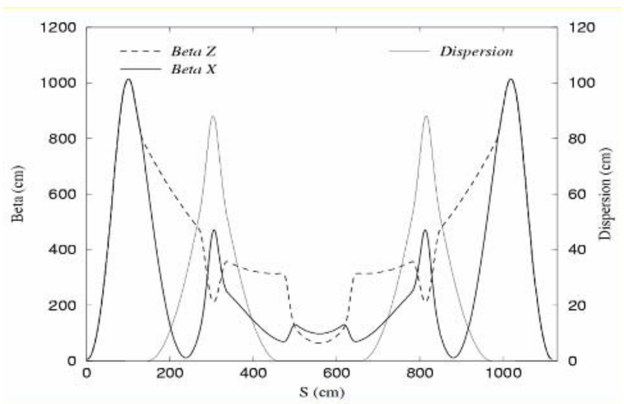

Figure 3. Lattice functions of VEPP-2000 (half period).

An essential advantage of the found optics is zero dispersion in the IRs, RF cavity, and injection straight sections.

The chosen optics has another very useful feature. Variation of the focusing strength of the solenoids changes β^* and the beam emittance in inverse proportion at fixed energy. Changing energy, we can squeeze β^*, conserving the maximum beam size in the solenoids, thus giving a possibility to tune optics for better performance. Apparently, this feature provides the luminosity scaling at lower energies approximately as γ^2 (instead of γ^4 for the option with fixed β^* (Fig. 4).

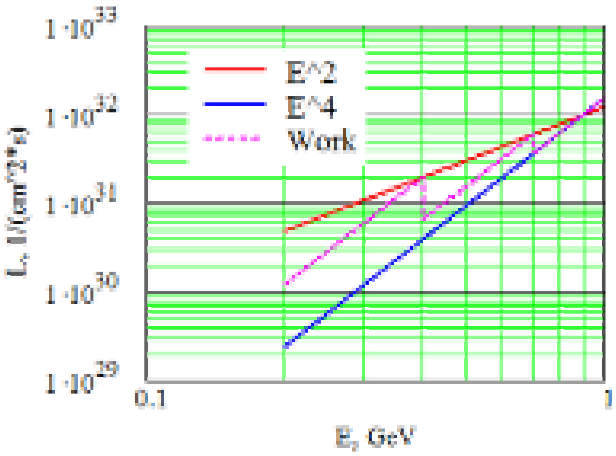

Figure 4. Scaling of the VEPP-2000 luminosity with energy.

The main parameters of the new collider are given in Table 1

Parameter	Value
Circumference	$24.38m$
RF frequency	$172MHz$
RF voltage	$0.1MV$
Momentum compaction	0.036
Synchrotron tune	0.0035
Energy spread	6.4×10^{-4}
Beam emittances (x,y)	$1.29\times10^{-7}m$
Dimensionless damping decrements (x,y,z)	2.19×10^{-5} 2.19×10^{-5} 4.83×10^{-5}
Betatron tunes	4.05 , 2.05
Betatron functions @ IP	$0.1m$
Bunch population	1.0×10^{11}
Luminosity per IP	$1.0\times10^{32}cm^{-2}s^{-1}$

Table 1. Main parameters of VEPP-2000.

BEAM-BEAM SIMULATIONS

The above arguments in favour of RCB have been checked out by computer simulations of the beam-beam effects in the VEPP-2000 collider lattice [5,6]. Both weak-strong and strong-strong cases have been studied using two codes. The strong-strong code is the modified BBSS by K.Ohmi [7]. The weak-strong case has been addressed by means of Shatilov's LIFETRAC [8] and BBSS.

The main results of the simulations are presented in Figs. 5-8. For the weak-strong case the emittance of weak beam is plotted against the beam-beam parameter (Figs. 5,6). One can see that the beam blow-up for round beam is rather moderate even at $\xi = 0.2$. Taking into account the machine nonlinearities represented by sextupoles does not change the beam behaviour very much.

The strong-strong calculation proves the advantage of the round beam and predicts the design luminosity of VEPP-2000 to be achieved at $\xi \approx 0.1$ (Figs. 7,8).

The simulations have also demonstrated stability of RCB against the ``flip-flop" effect, similarly to conclusions from simple flip-flop models [9].

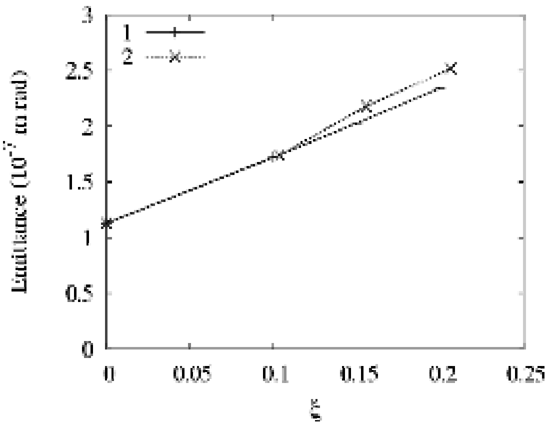

Figure 5. Emittance of weak beam vs. ξ (sextupoles “off”). 1-LIFETRAC, 2-BBSS.

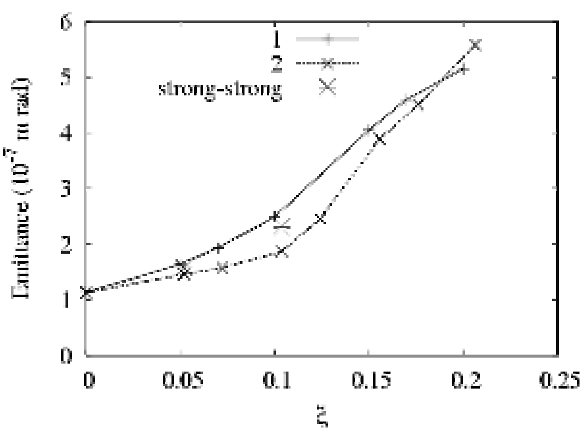

Figure 6. Emittance of weak beam vs. ξ (sextupoles “on”). 1-LIFETRAC, 2-BBSS

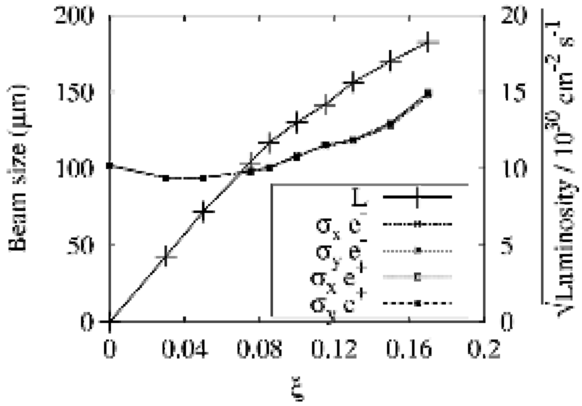

Figure 7. Beam size and $\sqrt{L}$ vs. ξ (sextupoles “off”).

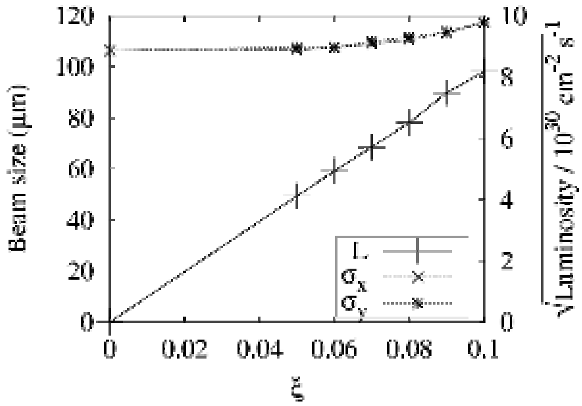

Figure 8. Beam size and $\sqrt{L}$ vs. ξ (sextupoles “on”).

ELEMENTS OF THE RING

Magnets

The lack of space for placing the new machine lead to demand on using of strong dipole magnets. For the energy of particles in the beam to be 1 GeV the field of a magnitude 2.38 T is needed. Such magnets have been designed, manufactured, tested and installed in the experimental hall. Figures 9,10 show the view of the dipole and the excitation curve.

Figure 9. 2.4 T dipole magnet.

Magnetic measurements confirmed the field calculation done by 3D code MERMAID. The measured field uniformity is of the order of 10^{-4} at the top field level in the aperture $\pm 1.5cm$.

All 24 quadrupole magnets have been produced. After magnetic measurements, some correction was required to improve the field quality in the required aperture. This was done by adding facets.

The chromaticity correction sextupoles have been received from the machinery workshop recently and undergo tests and measurements.

Due to deficit of free space in the ring, all magnets have additional steering coils: dipoles and quadrupoles conatin dipole correctors, skew-quads are combined with sextupoles.

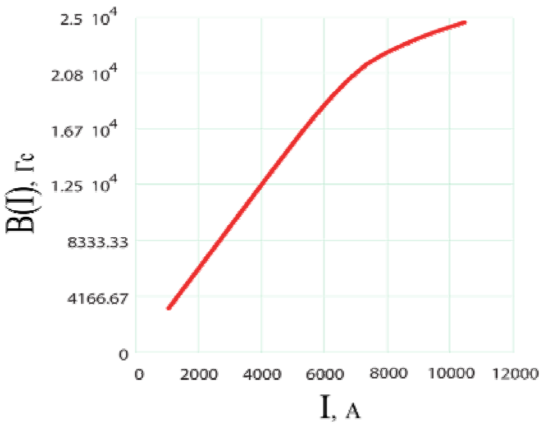

Figure 10. Excitation curve for the dipole. (Units on the vertical axis – Gs).

Solenoids

Each solenoidal block consists of a main solenoid which is longitudinally divided into two parts, and a compensating solenoid with reverse field to adjust longitudinal field integral and focussing (Fig. 11). Such a scheme gives an additional possibility to control the β^* value by feeding only one half of the main solenoid at lower energies.

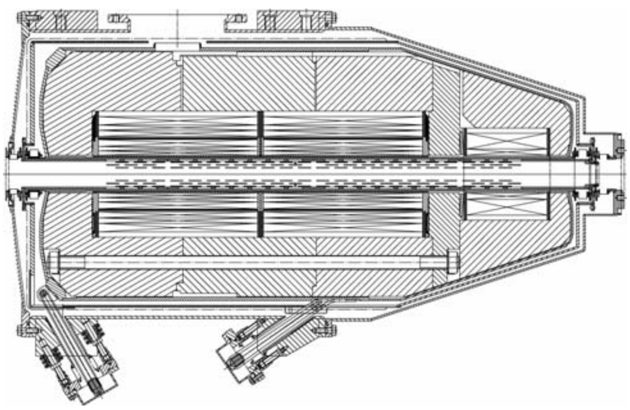

Figure 11. View of the solenoid.

A prototype solenoid (a half of the main coil) has been manufactured and tested. The design field of 13T has been achieved and now the design is adopted and the coils are being produced.

RF System

The accelerating field frequency is 172MHz at the 14th harmonic of the revolution frequency. The normal-conducting single mode RF cavity have been manufactured and is now under cold testing.

Vacuum System

The high-vacuum system consists of 16 ports with ion-getter pumps which are located at the edges of bending magnets vacuum chambers; of one ion-getter pump connected to the RF cavity; and of 4 cryopumps formed by cool solenoid surface. To prevent heating of the cryosurface which is under 4.2 K by SR a perforated liner cooled with the liquid nitrogen is used. The liner ports should provide linear pumping rate of 5 l/s/cm for the nitrogen.

Beam Injection

The beams will be injected into the storage ring in horizontal plane into the long drift opposite to the RF cavity. The inflector plates are placed on the inner side of the vacuum chamber in the bending magnets at the ends of the drift. The advantage of such a scheme is independence of the injected beam trajectory on the solenoids field.

The HV pulse generator for the injection system with 50 kV pulse amplitude and duration of 40ns have been tested and is being prepared for installation.

FUTURE POSITRON SOURCE

The rate of particle losses in the VEPP-2000 collider at the design luminosity is estimated as $\approx 10^8 s^{-1}$ (beam life time $1.1 \times 10^3 s$). The main sources are the Touschek effect, gas bremsstrahlung and single beam-beam bremsstrahlung. Existing injector is capable of supplying the positrons at the rate which is one order of magnitude smaller than necessary. To provide the required amount of positrons a transfer channel from the VEPP-5 preinjector complex is being built. At the moment, one half of the tunnel is ready. The channel lattice has been designed and manufacturing of the magnets is in preparation.

SUMMARY

Main magnetic elements of the VEPP-2000 storage ring are ready and the collider is being assembled. The superconducting solenoid prototype has been tested and reached the design field. The RF system is under testing and will be ready for installation soon. The power supplies are produced.

The collider will start operation with existing injector which will provide positrons at the rate sufficient to maintain luminosity of $10^{31} cm^{-2} s^{-1}$. The transfer channel from the new positron source is being built.

Under favourable conditions we plan to have the first beam in VEPP-2000 by the end of 2004.

REFERENCES

[1] P.M.Ivanov *et al.*, in: Proc. 3rd Advanced ICFA Beam Dynamics Workshop, Novosibirsk, (1989), p. 26.

[2] L.M.Barkov *et al.*, in: Proc. 14th HEACC, Tsukuba (Japan), (1989), p.1385.

[3] L.M.Barkov *et al.*, in: Proc. PAC91, San~Francisco (1991), p.183

[4] V.V. Danilov *et al.*, in: Proc. EPAC'96, Barcelona (1996), p.1149.

[5] A.Valishev, E.Perevedentsev, K.Ohmi, in: Proc. PAC’2003.

[6] I.Koop *et al.*, ICFA Beam Dynamics Newsletter No. 31, August 2003, p. 10.

[7] K.Ohmi, Phys. Rev. E **59**, 7287 (2000)

[8] D.Shatilov, Part. Accel. **52**, 65 (1996)

[9] A.V.Otboyev and E.A.Perevedentsev, in: Proc. PAC99, New York (1999).