BOOSTER OF ELECTRONS AND POSITRONS (BEP) UPGRADE TO 1 GEV*

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Abstract

At present new electron and positron injection complex at BINP is commissioned and ready to feed VEPP-2000 collider with intensive beams with energy of 450 MeV. To obtain peak luminosity limited only by beam-beam effects in whole energy range of 160-1000 MeV and to perform high average luminosity with small dead time the top-up injection is needed. Booster BEP upgrade to 1 GeV includes modification of all magnetic elements, including warm dipoles magnetic field increase up to 2.6 T, vacuum chamber, RF-system, injection-extraction system. BEP comissioning is scheduled to the end of 2014.

INTRODUCTION

VEPP-2000 electron positron collider [1] was commissioned and spent three successful runs 2010-2013 collecting data at whole energy range of 160÷1000 MeV per beam [2]. During this work VEPP-2000 used the injection chain of its predecessor VEPP-2M [3]. That machine worked at lower energy (< 700 MeV) and showed luminosity 30 time lower than designed value of 10^{32} $cm^{-2}s^{-1}$ for VEPP-2000 at 1 GeV. As a result the positron production rate was not enough to achieve beams intensity limited only by beam-beam threshold. This restriction will be cured by link up via 250 m beamline K-500 to the new injection complex VEPP-5 [4] capable to produce intensive electron and positron high quality beams at energy of 450 MeV (see Fig. 1).

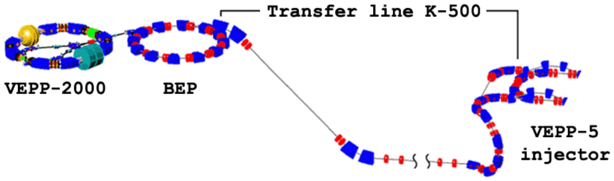

Figure 1: VEPP-2000 accelerator complex after upgrade.

Another VEPP-2000 efficiency limitation comes from maximal energy of the booster ring BEP [5] limited at the value of 800 MeV. Even with unlimited beams production rate beam-beam parameter being at the threshold after injection inevitably decrease after acceleration in the collider ring $\xi \propto 1/\gamma^2$. In addition dead time during acceleration process and the complexity of acceleration of colliding beams close to the threshold mean the necessity of the top-up injection.

BEP OVERVIEW

Booster synchrotron BEP dedicated to capture, cooling and storage of hot 125 MeV positrons from conversion system operated since 1991. It consists of 12 FODO cells. Each cell houses 30° sector dipole, two quads and straight, used for RF-cavity, kickers, injection/extraction septum, diagnostics, vacuum pumping. Booster layout is presented in Fig.2, main parameters are listed in Table 1.

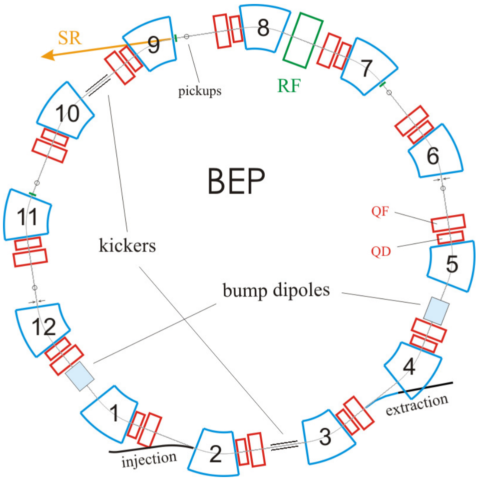

Figure 2: Booster synchrotron BEP layout.

Table 1: Modified BEP Main Parameters @ 1 GeV

Parameter	Value
Perimeter, Π	22.35 m
Revolution frequency, f_0	13.414 MHz
Bending radius, r_0	128 cm
RF harmonic, q	13
Synchrotron radiation loss	70 KeV/turn
Emittances, ε_x, ε_y	$8.6 \cdot 10^{-6}$, 10^{-8} cm
Betatron tunes, ν_x, ν_y	3.4, 2.4
Momentum compaction, α_p	0.06

MAGNETIC SYSTEM

To achieve the target beam energy all magnetic elements should be significantly strengthened. The main idea of magnets upgrade is the use of existing coils, power supplies and whole infrastructure. Fields increase

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arises both from iron reshaping with aperture reduction and feeding current boost up to 10 kA.

Dipole Magnets

Dipole magnets modification includes four steps (see Fig. 3). 1) 4 mm iron plates are mounted on the poles planes to reduce gap from 40 mm to 32 mm. 2) Poles are narrowed from 120 mm to 90 mm for better concentration of field flux. 3) 11 mm iron plates are installed at the end face planes to lengthen the magnet. This action required to throw out existing dipole correction windings to free space in longitudinal direction. 4) Massive iron blocks fixed at inner side of yoke to weaken its saturation.

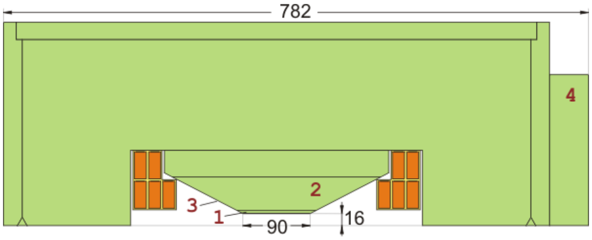

Figure 3: Dipole magnet vertical cross section.

Armco steel permeability table *μ(H)* was finely tuned after the maximum field in the centre of first modified prototype magnet measurements by NMR probe (Fig. 4) and field distribution measurements were made with carriage of Hall sensors (see Fig. 5).

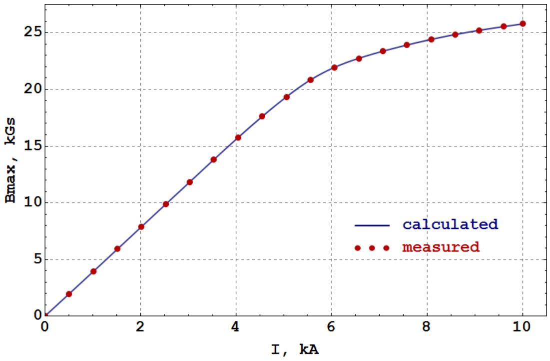

Figure 4: Dipole maximum field current dependence.

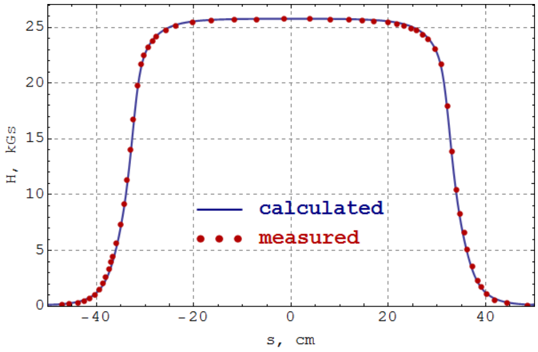

Figure 5: Field longitudinal distribution $B_y(s)$ at 9.9 kA.

New dipole correction coils are designed not around the poles but on the return yoke (not shown in Fig. 3).

Quadrupoles

Focusing doublet consists of "small" D-quad and "large" F-quad, originally with inscribed diameters ratio as well as windings turns number ratio equal to 2:3. The sextupole fields needed for chromaticity correction are introduced into quads by special poles profile. Assuming ideal equipotential surface at the pole one can find in 2D approximation two asymmetric profile curves

$$x_{out,in}(y) = -\frac{G}{S}\left(1-\sqrt{1\pm\frac{S}{G}\frac{R^2}{y}+\left(\frac{S}{G}\right)^2\frac{y^2}{3}}\right).$$

Here *G* and *S* are linear and sextupole gradients, R is inscribed radius, *x* and *y* for horizontal and vertical coordinates.

Unfortunately with the field increase and corresponding iron saturation sextupole field component $P_6 = \partial^2 B_y/\partial x^2$ saturates much stronger than quadrupole one (see green line in Fig. 6). Head-tail instability caused by insufficient sextupoles strength was one of the strongest restrictions for BEP energy upper limit. Quads modification includes aperture reduction (84 mm → 74.8 mm, 56 mm → 52.9 mm) as well as sextupole component increase by profile reshaping (see Fig. 7). Final design quads field gradients are $G_{QD} = -4.51$ kGs/cm, $P6_{QD} = -0.175$ kGs/cm^2; $G_{QF} = 3.21$ kGs/cm, $P6_{QF} = 0.078$ kGs/cm^2.

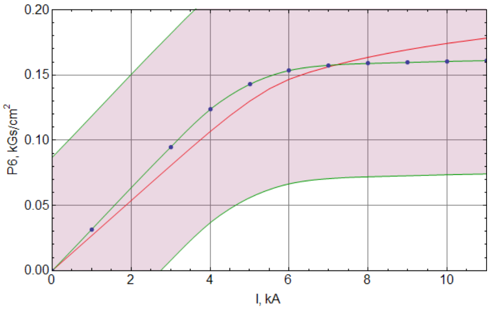

Figure 6: QD sextupole component saturation.

Main efforts of quadrupole modification were aimed to reproduce strongly nonlinear saturation curve of dipole (Fig. 4) in whole energy range due to series feeding of all magnetic elements by single power supply. The difference in normalized fields should lie within 0.5% at top energy due to severe weakening of correction coils on saturated iron. That was achieved by return yoke reshaping.

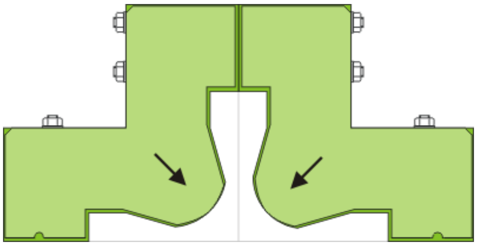

Figure 7: QF quadrupole yoke reshaping.

BUMP Magnets

Slow-pulsed closed orbit distortion of ~25 mm in horizontal direction (so called "bump") is needed for beam extraction. Old system of additional windings in 4 dipoles becomes very ineffective at high energy due to strong iron saturation. Instead two 30 cm pulsed (2.5 ms) laminated C-shape magnets will be installed with 1.7 kGs field (see Fig. 2).

VACUUM SYSTEM

One cell vacuum chamber consists of extruded aluminium segment inside dipole and focusing doublet and stainless steel chamber with pumping equipment port. To use the old system after components modernization aluminium chamber (a) deformed locally inside dipole magnet (b) and small quad QD (c) (see Fig. 8). In order to decrease QD strength and reduce deformation the BEP working point was moved from (3.46, 2.85) to (3.4, 2.4).

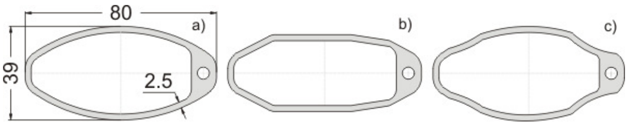

Figure 8: Vacuum chamber cross-section.

RF SYSTEM

Since the energy loss increases at higher energy and achieves 70 KeV/turn new copper RF cavity was manufactured in BINP workshops (see Fig. 9). It will operate with 174.376 MHz frequency and 110 kV voltage.

Figure 9: New BEP RF cavity.

INJECTION / EXTRACTION

New injection septum magnet is needed to receive 450 MeV beams from VEPP-5. 25° pulsed magnet with 10 mm aperture and field value of 34 kGs is completed and will be installed after magnetic measurements. Extraction system remains completely unchanged.

DIAGNOSTICS

Beam diagnostic system based on 6 CCD-cameras, and 5 electrostatic pickups remains unmodified.

SR BEAMLINE

For different material science applications the synchrotron light beamline was designed from one of the bending magnets (see Fig. 2). The line fortunately goes between yokes of dipole and QD lens, only vacuum chamber should be modified.

TRANSFER LINE BEP-VEPP

The transport of accelerated to 1 GeV bunches from BEP to VEPP-2000 collider needs significant modernization of transfer line. The most important one is the manufacturing of new bending magnets (17.2°, 41.2°) with the same radius and field as BEP dipoles but smaller gap of 12.8 mm and 2 turns/pole coil instead 5 turns/pole in BEP dipoles. Fed in series with BEP magnets channel's ones should have the same field-current dependence. The achieved difference in effective field is presented by blue line in Fig. 10. Corridor shows the correction coils ability.

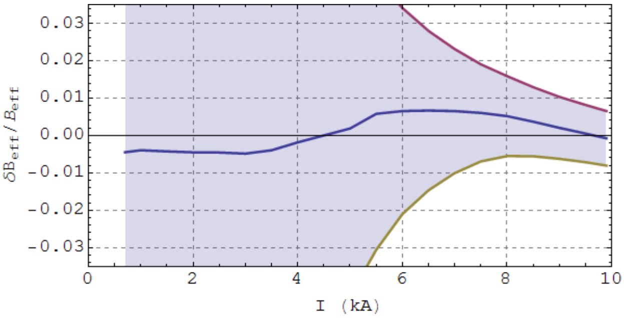

Figure 10: Difference in two type dipoles effective field.

CONCLUSION

At present the VEPP-2000 booster BEP is disassembled and passing through deep modernization to achieve top energy of 1 GeV, provide top-up injection and designed luminosity of the electron-positron collider. Magnetic elements and vacuum chamber prototypes successfully tested and showed designed parameters. Beam commissioning is scheduled to the end of 2014.

REFERENCES

[1] Yu. Shatunov et al., "Project of a New Electron-Positron Collider VEPP-2000", EPAC'2000, Vienna, Austria, p.439.

[2] A. Romanov et al., "Status of the Electron-Positron Collider VEPP-2000", NaPAC'2013, Pasadena, USA, p.14.

[3] G.M. Tumaikin et al., HEACC'1977, Serpukhov, USSR, p.443.

[4] A. Starostenko et al., "Status of Injection Complex VEPP-5: Machine Commissioning and First Experience of Positron Storage", these proceedings (MOPME073).

[5] V.V. Anashin et al., "Damping Ring for Electrons and Positrons BEP", BINP preprint 84-114, Novosibirsk, 1984.