MAGNET STRUCTURE OF THE VEPP-2000 ELECTRON-POSITRON COLLIDER

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Abstract

Electron-positron collider VEPP-2000 with beam energy up to 1 GeV is under commissioning at Budker Institute. This paper presents magnetic elements of the storage ring including 13T focusing superconducting solenoids in interaction regions. Features of magnet elements design and magnetic measurements results are given together with comparison to previously calculated data.

VEPP-2000 PROJECT CONCEPT

Since the end of 1974 the e^+e^- collider VEPP-2M in Novosibirsk has been successfully running in the c.m. energy range from threshold of hadron production up to 1.4 GeV. The integrated luminosity of about 74pb^{-1} was collected with two modern detectors SND and CMD-2 allowing precise measurements of most of the hadronic channels of e^+e^- annihilation.

VEPP-2000 project [1,2] is a further development of the facility dedicated to improve the luminosity and in the same time increase the maximum attainable energy up to 2GeV, that will significantly broaden the potential of experiments performed at the collider. Moreover this ring will allow to check the concept of round colliding beams [3].

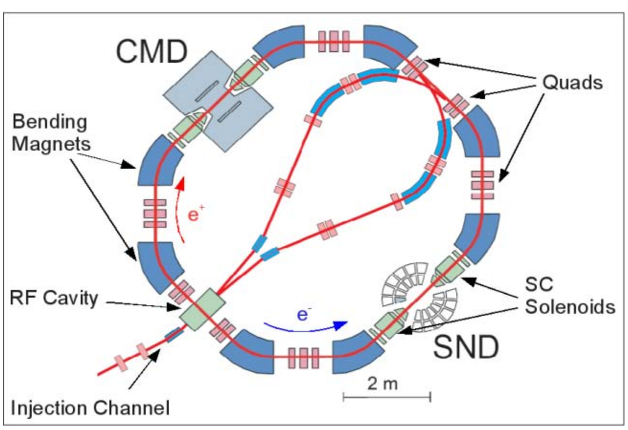

Fig. 1: General layout of VEPP-2000 storage ring

Constrained VEPP-2M complex area restricts the machine dimension leading to necessity of using strong dipole magnets. To achieve the beam energy of 1 GeV a guiding field of 2.4 T is required. Arc lattice includes 5 families of quadrupoles with the maximum gradient of 50T/m that can be varied independently. The chosen optics has an advantage of zero dispersion in IRs, RF cavity and injection straight sections. Final focusing is made with use of 13T superconducting solenoids.

Three families of sextupoles are installed in the ring. The chromaticity correction is performed by the sextupole families S_x and S_z , placed near the quadrupole triplets, where the dispersion function is non-zero. Another set of sextupoles is placed in dispersion free regions and is used to improve the dynamical aperture.

Fine tuning of the machine optics is proposed to be made with 20 horizontal and 20 vertical dipole corrections combined with quadrupoles. For correction of the guiding field 8 additional horizontal dipole corrections are installed in the bends.

BENDING MAGNETS

VEPP-2000 is a circular machine and it has 8 bending magnets turning orbit 45° each. VEPP-2000 is assembled in the same working hall as its predecessor VEPP-2M. Due to this reason the size of the collider is limited, circumference is just 20 meters, and bending radius of orbit is rather small for 1GeV particles – 1.4 meter. With such a radius, we need to have the bending field of 2.382T on the orbit to work at full energy.

Magnet yoke is O – shape with 4 cm gap between the poles. Selected profile of the pole cross-section makes it possible to achieve the desired 2.382 T field and to suppress nonlinear components of magnetic field so that the homogeneity is $5\cdot10^{-4}$ over all aperture. Working current for 1GeV is 9 kA leading to necessity of strong water cooling to prevent overheating.

Fig. 2: Bending magnet

In Fig. 3 you can see the saturation curve of the magnet showing the dependence of magnetic field on the orbit on the current in the coils. A new power source has been constructed with a capability to provide a current up to 10kA preserving the relative stability of field 0.0001 at all working energies. The measurements have shown that the maximum achievable field with current of 10kA is 2.45 T.

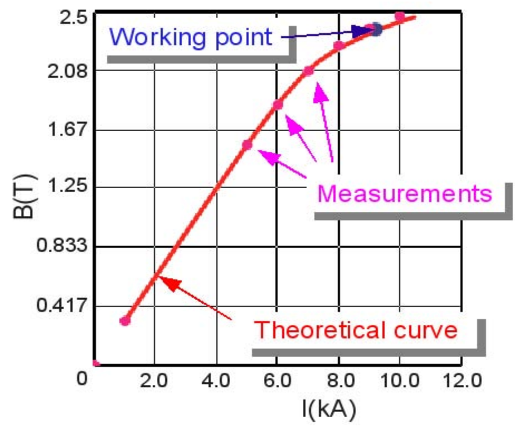

Fig. 3: The saturation curve of the magnet

Before installation in the ring a distribution of vertical component of the field at the median plane was measured for every magnet. Measurements have shown that values of the field are close to those computed. Parasitic sextupole and decapole components for all magnets stay in range of $5\cdot10^{-4}$ relative to guiding field within ±2cm deviation off the main orbit for 2.382 T and even better at lower energies.

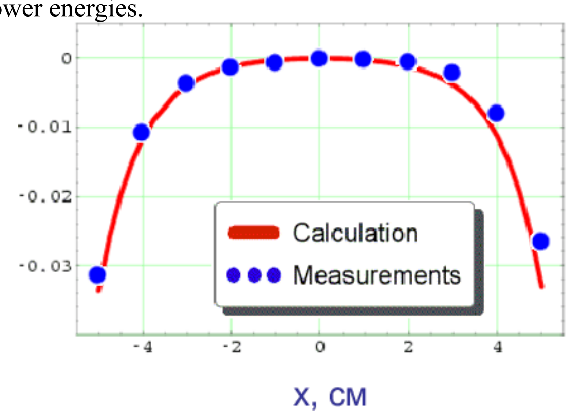

Fig. 4: Transverse distribution of vertical magnetic field inside the magnet for 1GeV

Calculations have shown that effect of these nonlinearities can be compensated by the sextupoles installed in the ring. Guiding field errors at the edges of the magnets provide a small effect on the beam dynamics. Measurements have shown that at high energies a small but not negligible linear gradient of the field appears in the magnet due to asymmetry of highly saturated yoke in a sector type bending magnet. This leads to small additional focusing of the horizontal betatron motion.

SUPERCONDUCTING SOLENOIDS

Creation of SC-solenoids is the most complicated task among all of technical problems that have been solved during construction of VEPP-2000 because they generate an extremely high magnetic field and have to be integrated with existing particle detectors.

The collider lattice includes four blocks of solenoids, two at each of interaction regions symmetrically to IP. Every block consists of two main solenoids, one compensating solenoid, iron yoke and cryogenic system. The main solenoids are 256 mm long and produce the magnetic field for finale focusing. The compensating solenoid produces the field opposite to that of the main solenoid to equate an integral of longitudinal field through all the block to the value required to turn the betatron oscillation plane by $\pi/4$.

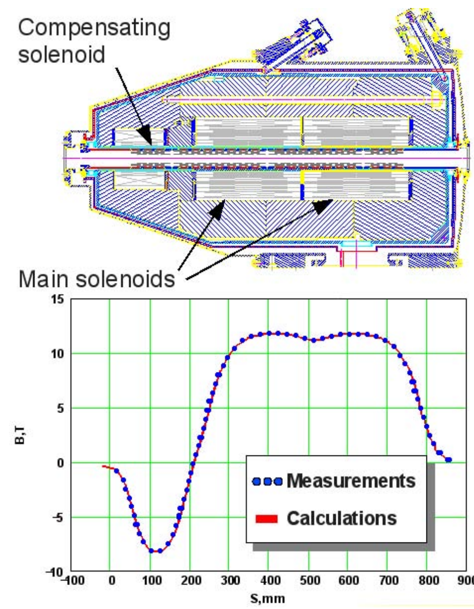

Fig. 5: SC-Solenoid and distribution of its longitudinal magnetic field

Each of the main solenoids is divided to five coils by radius. Three internal coils are made of multistring Nb_3Sn wire implanted in a copper matrix with diameter of 1.24 mm. Two outer coils are made of NbTi wire with diameter of 1.26 and 0.92 mm. The compensating solenoid is made of two NbTi coils with the same properties. Nb_3Sn and NbTi parts of main solenoids are powered independently with two sources of current with high stability. The third power supply is used to feed the compensating solenoid. Such a scheme averages inaccuracy in the number of turns of wire in different coils and allows to flexibly tune the integral of longitudinal magnetic field in every block of solenoids.

The cryogenic system is organized in such a way that all solenoids and iron yokes are placed in a helium volume. The inner pipe of this volume is a part of the vacuum chamber. This helium surface also provide a good pumping at the interaction point. A special copper shielding with the temperature of liquid nitrogen protects the helium volume from a synchrotron radiation. Each block of solenoids has its own buffer vessel for 200 litres of liquid helium. Wires of power supply enter the block at the top of these cryostats. The system for helium refilling is also placed there so that each block can be supplied with liquid helium independently. Consumption of liquid helium is approximately 2 litres per hour for one block.

QUADRUPOLE MAGNETS

Arcs of VEPP-2000 storage ring comprise 24 quads of three different types. Each half of the arc represents double-bend achromat with the triplet of quads in the middle. Two doublets of quads are installed in the injection and the RF-cavity regions. All of these quads have an aperture of 4 cm and can achieve the magnetic field gradient up to 55 T/m. 16 quads have the length of 14 cm and four, by one in the middle of each triplet, have the length of 19 cm.

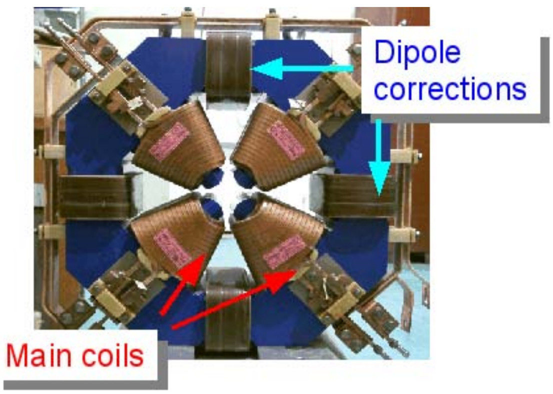

Fig. 6: VEPP-2000 quadrupole magnet

Each quadrupole is supplied with an individual power source with the stability of 10^{-4} in all range of ±300A. Such an approach allows to have flexible ring optics without additional quadrupole correctors. Four other quads with low gradients are installed in the interaction regions between solenoids and arcs to split equal vertical and horizontal β-functions.

In spite of the fact that main quads have rather wide poles with hyperbolic shape, magnetic measurements have shown that the field has nonlinear components. It is partly explained by the edge effects. After some simulations a solution with a special shape of the pole edges was found providing suppression of nonlinearities by ten times.

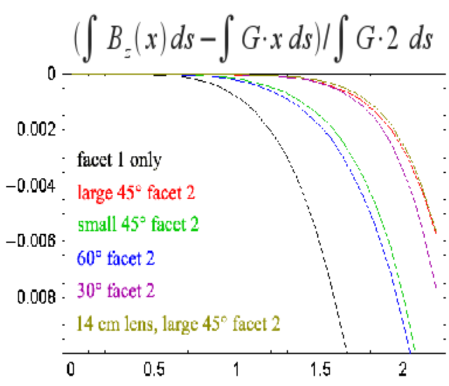

Fig. 7: Magnetic field quality for different variants of pole shape.

Due to lack of free space in the ring, dipole correctors needed to compensate magnetic element position errors and for fine tuning of beam orbit are integrated with quads and bending magnets which have additional coils for this purpose. Fields of these corrections include a strong sextupole term in addition to the main dipole component. Maximal dipole field component at the current of 4A amounts to 0.06 T, with the sextupole gradient of 0.25 kT/m^2. Its effect on beam dynamics is comparable with the effect of the main sextupoles.

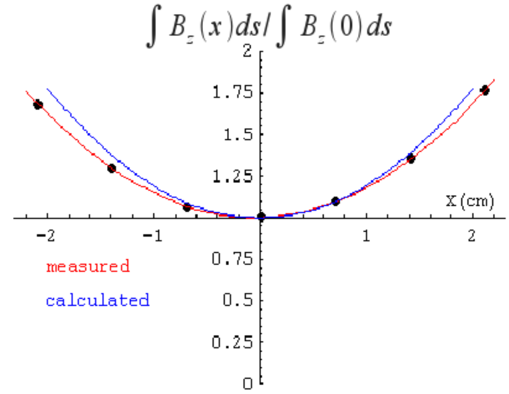

Fig. 8: Quality of magnetic field in correctors

SEXTUPOLE MAGNETS

Three families of sextupoles are used in the storage ring. Sx and Sz sextupoles are installed in the arcs where the dispersion function is high and are dedicated to suppress chromaticity. To widen the dynamic aperture, the third sextupole family is applied in the injection and RF-cavity straight sections. Sx and Sz sextupoles achieve values of gradient up to 2 kT/m^2 with the effective length of 54 and 91 mm correspondingly. Cross-sections of all sextupoles are identical. Two additional coils are integrated in the opposite poles of the lens to create a skew correction.

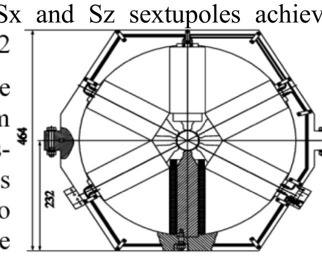

Fig. 9: Sextupole sketch

CONCLUSION

In the present state all magnets and solenoids are installed to the ring and powered. Conducted tests have shown that all parameters are in the good correspondence to the project values. The control system that will integrate operations with bending magnets, solenoids and quads is in the final stage of development.

REFERENCES

[1] Yu. M. Shatunov et. al., “Project of a New Electron-Positron Collider VEPP-2000”, in Proc. EPAC2000, Vienna, 26-30, June, 2000, p. 439

[2] VEPP-2000 official web page. http://vepp2k.inp.nsk.su

[3] V.V. Danilov et. Al, “The Concept of Round Colliding Beams” in: Proc. EPAC'96 Barcelona, 1996, p. 1149.