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NEW QUADRUPOLES INSTALLED AT VEPP-2000 FOR HIGH ENERGY OPERATION WITHOUT FINAL FOCUS

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Abstract

The family of four weak quadrupoles was replaced at VEPP-2000 electron-positron collider with new one. New quads with increased bore diameter made with higher field quality and equipped with fiducial points are excited by water-cooled coils fed with new 300 A power supplies. That allowed to double integrated gradient and to implement so called "warm" operation mode (with switched-off final focus solenoids) above 500 MeV energy level. Presented in the paper "warm" modes are used for beam scrubbing and for resonance depolarization technique of Compton backscattering beam energy measurement system cross-calibration.

INTRODUCTION

VEPP-2000 is a small, 24 m perimeter, single-ring electron-positron collider with energy range of 150-1000 MeV per beam [1-6]. It operates with round beams and uses solenoids for final focusing [7]. The layout of the VEPP-2000 collider is presented in Fig. 1.

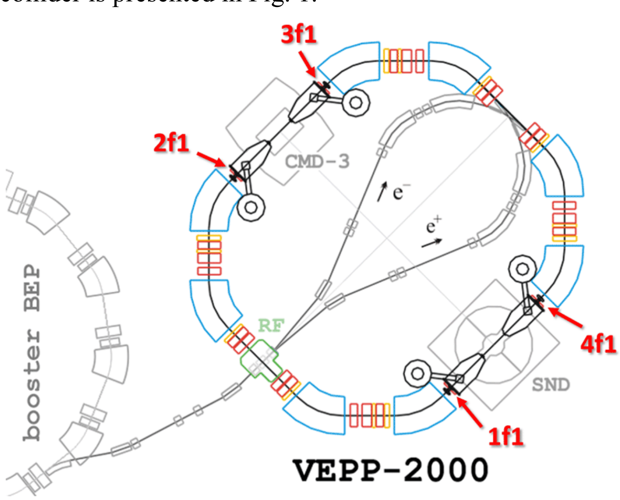

Figure 1: VEPP-2000 storage ring layout.

For the beam scrubbing after long shutdowns and resonance depolarization energy calibration technique [8] the special "warm" regime was proposed with final focus (FF) solenoids switched off. In this mode the family of weak quads (f1, see Fig. 1) is significantly stronger than in regular lattice that did not allow to use this regime above 500 MeV.

Compton Backscattering System

Beam energy at VEPP-2000 is measured online by the Compton backscattering (CBS) system [9]. In Fig. 2, one can find the typical edge of the spectrum of scattered photons. The oscillations in the left part are produced by interference of the MeV-scale scattered photons due to interaction of electrons with laser radiation along the curved path inside the dipole.

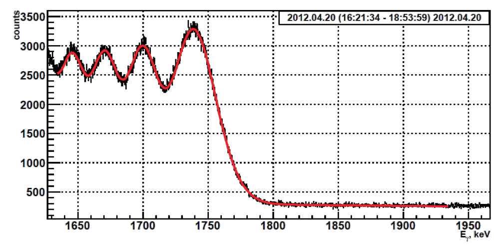

Figure 2: Compton backscattering measurements.

For cross-check of CBS system the resonance depolarization (RD) technique is used [10]. In Fig. 3 an example of three depolarizations is shown with different speed and direction of depolarizer frequency scan.

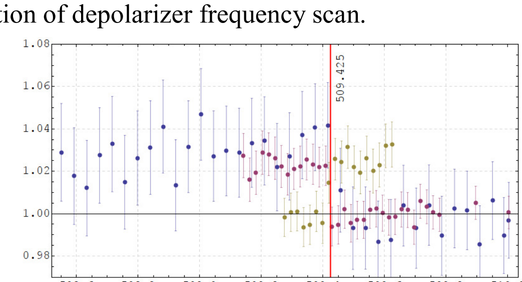

Figure 3: Resonance depolarization at VEPP-2000.

Unfortunately, it was found that RD can't be used for precise energy calibration in regular operation regime of VEPP-2000 due to residual closed orbit distortions inside FF solenoids. Nevertheless, in special "warm" mode the cross-check of all three energy control methods is carried out (see Fig. 4). Third method is based on precise magnetic field control by NMR probes in all dipoles. It is usually used for fast online control of relative energy variation.

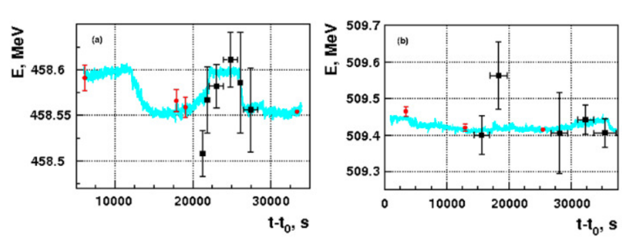

Figure 4: Beam energy control by CBS (black), RD (red) and NMR (blue) systems.

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Motivation for Quads Replacement

New f1-quads were developed produced and installed in order to solve several issues simultaneously:

1) Bore diameter increase to 50 mm that allow to align quads independently to nearby solenoids
2) Fiducial points precisely referenced to magnet axis.
3) Gradient increase due to high current water-cooled coils and new 300 A power supplies.
4) Field quality enhancement by accurate poles profiling, machining and control.

NEW QUADS DEVELOPEMENT

The main limitation for new quads developments comes from very tight components arrangement at VEPP-2000 machine. Initial design proposed that quads are installed tightly around precisely machined massive water-cooled copper piece of vacuum chamber. Later it became clear that alignment of nearby solenoids can't be done without shift of f1-quad. New quads has increased bore diameter and aligned independently.

The quad is very short, 44 mm along the iron. Thus the fringe fields are important. The 3D-optimization of side and fringe chamfers to achieve target field quality was done (see Fig. 5). All the magnetic field calculations were done via *MERMAID* code [9].

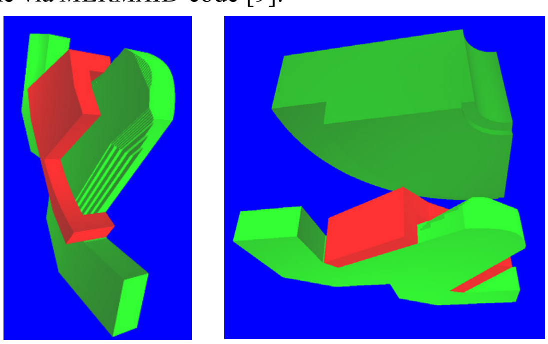

Figure 5: Model for 3D-calculation.

Significant effect on the field longitudinal distribution was found due to the return yoke of the solenoid. Although the yoke is a cold mass and hidden inside the cryostat the distance to the f1-quad is not very large. The integrated field reduction was found at the level of ~0.5%. In Fig. 6 one can notice the asymmetry of longitudinal gradient distribution.

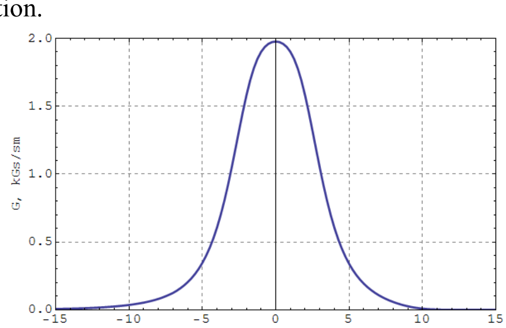

Figure 6: Longitudinal gradient distribution.

The calculated field quality across the aperture is shown in Fig. 7. The nonlinear harmonics relative contribution achieve 3×10^{-3} at the radius r = 20 mm, that is still several times better than for old type.

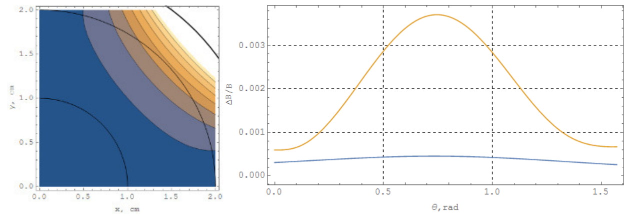

Figure 7: Field quality: 2D-map (left, contours every 10^{-3}), azimuthal dependence for two radii r = 10/20 mm (right).

Designed 3D-model and manufactured quad at BINP workshop are presented in Fig. 8.

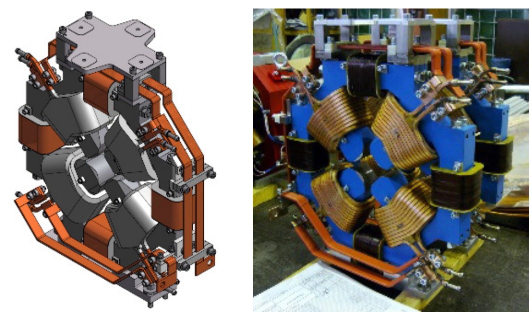

Figure 8: Quads 3D-model (left) and the result (right).

All the quads were measured with rotating coil measurement system. The resulting excitation curve is presented in Fig. 9 in comparison to calculated one.

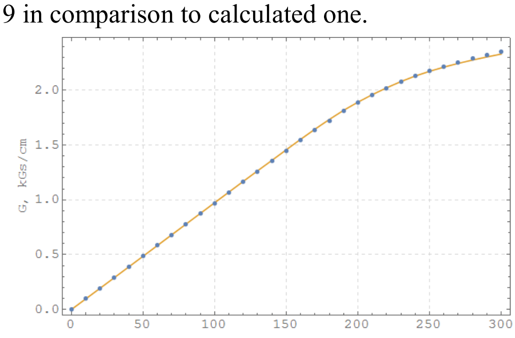

Figure 9: Quads excitation curve, measured (dots) and calculated (solid curve).

The relative quad-to-quad difference as a function of excitation current is drawn in Fig. 10, it does not exceed 10^{-3}.

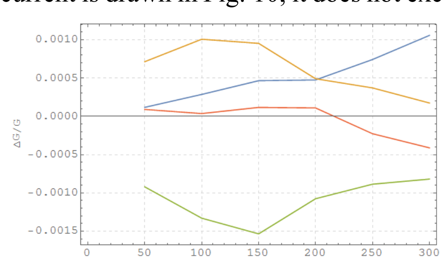

Figure 10: Quadrupoles difference.

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Finally the new f1-quads were installed at VEPP-2000 (see Fig. 11) and the run 2017/2018 was successfully carried out.

Figure 11: The 3f1-quad installed in tight surroundings.

WARM LATTICES

The "traditional" lattice used for machine commissioning suggests: switched-off one of triplet's quads; large dispersion at interaction region; almost unperturbed optics at injection region. That allows regular injection and stacking of a single beam. Disadvantages of this lattice are: too strong f1-quad family; very large momentum compaction α_p = 0.176. Latter leads to insufficient longitudinal acceptance at high energy. The lattice functions of discussed operation mode are drawn in Fig. 12.

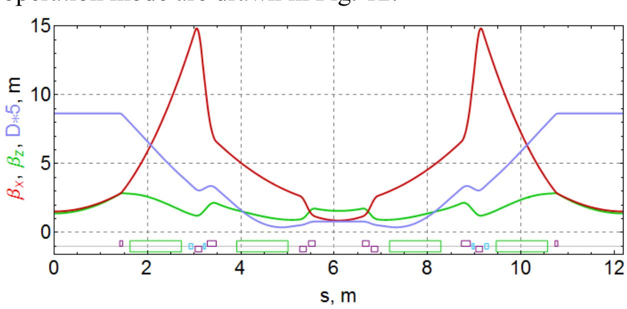

Figure 12: Lattice functions of "old warm" regime.

In order to overcome mentioned restrictions and to achieve high energy at VEPP-2000 without solenoids that is needed first of all for RD method applied to CBS system cross-check the new lattice was proposed. The lattice functions of proposed operation mode are presented in Fig. 13.

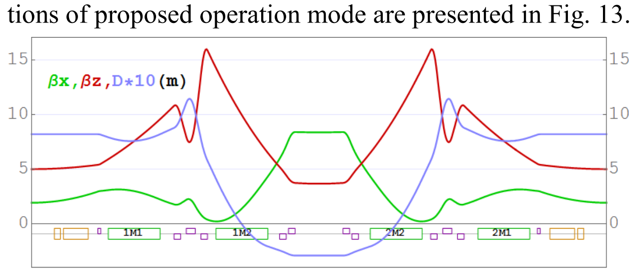

Figure 13: Quads excitation curve, measured (dots) and calculated (solid curve).

"New warm" lattice does not allow bunch stacking due to improper phase advance between kicker and injection point but gives lower momentum compaction: $\alpha_p = 0.1$.

The beam was successfully captured at the energy as high as 940 MeV where the measurements of various e^+e^- annihilation crossections behavior at the nucleon-antinucleon production threshold by both VEPP-2000 particle detectors SND and CMD-3 are carried out [12] and the energy control is important. In Fig. 14 one can see the beam sizes measured by CCD-based imaging system [13] in comparison to model. The emittances are equal due to the working point chosen at the coupling resonance.

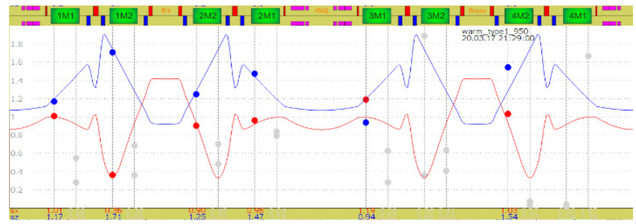

Figure 14: Model (solid lines) and measured (dots) horizontal (red) and vertical (blue) beam sizes at 940 MeV in "new warm" regime.

Although with the equal transverse emittances the acceptable for self-polarization beam lifetime ~5000 s was achieved the beam sizes are too large at this energy. It results in low rate of the Touschek counters used as polarimeters since the Touschek effect is not the main mechanism restricting beam lifetime.

CONCLUSION

The family of f1 quadrupoles was replaced at VEPP-2000 with higher performance one. Different “warm” regimes are available now for operation in total energy range for different applications.

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