LOW ENERGY LUMINOSITY AT VEPP-4M COLLIDER

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Abstract

VEPP-4M is an electron-positron collider intended for operation up to 5-6 GeV energy. Few years ago it was proposed to concentrate the facility efforts in the energy range of 1.5-1.8 GeV, which is perspective for HEP experiments. In the paper we present recent results on VEPP-4M operation in the low energy range.

1 INTRODUCTION

VEPP-4M collider [1] is a modified VEPP-4 machine. Initially the e^+e^- collider VEPP-4M was intended for the maximum energy of 6 GeV to study physics of Υ-meson and two-photon processes [2]. However, because of the strong interest in J/ψ and τ physics in recent years, it was proposed to concentrate the facility efforts in the low energy range of E=1.5–1.8 GeV [3]. This region is not typical for VEPP-4M and special beam studies are required to investigate the beam behaviour at low energy to optimise machine performance. Main parameters of VEPP-4M are given in Table 1.

Table 1: Main Parameters of VEPP-4M.

Parameters	Values	Units
Max. Energy	6	GeV
Circumference	366	m
Betatron tunes Q_X / Q_Y	8.54 / 7.58	
Momentum compaction factor	0.017	
Energy spread	0.1	%
Nat. chromaticities C_X / C_Y	-13 / -20	
RF-frequency	181.8	MHz
Harmonic number	222	
Energy loss	4	MeV/turn
Dumping time	0.002	sec
Number of bunches	2×2	
Particles / bunch	$1.5 \cdot 10^{11}$	
Luminosity	$2 \cdot 10^{31}$	$cm^{-2} \cdot sec^{-1}$
Interaction point		
β_Y function	0.05	m
β_X function	0.75	m
D_X function	0.80	m

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2 J/ψ TEST RUN

During future regular J/ψ and τ study we plan to calibrate the collider energy with an accuracy of 10^{-4} or better using the method of resonance depolarization [4].

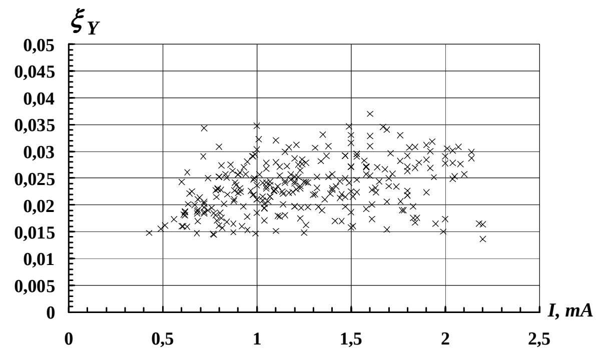

Figure 1: Test run vertical beam-beam parameter calculated from luminosity data.

According to the experiment scenario, such beam energy calibration has to be performed at the start and finish of every energy point run.

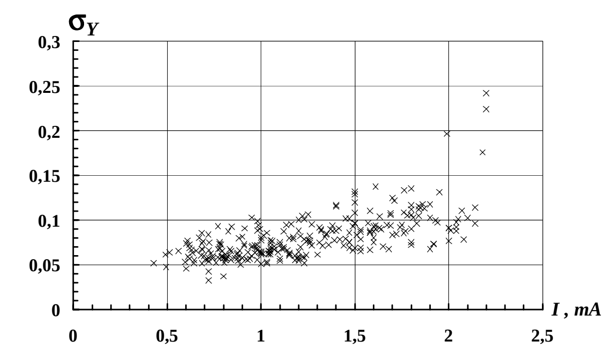

Figure 2: Test run vertical beam size (a.u.) calculated from luminosity data.

Polarized electron beams are injected to VEPP-4M from the VEPP-3 booster storage ring. The characteristic time of the radiation polarization for VEPP-3M at the maximum energy is about 20 min. The beam depolarization at VEPP-4M and registration of the scattering rate of the Touschek electrons provides the beam energy with the required accuracy.

To study the calibration method and to check the KEDR detector acquisition system, a J/ψ test run was performed in summer, 2001. Fig. 1 shows the beam-beam parameter obtained during this run, while Fig. 2 depicts the vertical beam size as a function of the bunch current (arbitrary units). Fig. 3 demonstrates a typical "jump" in the Touschek electrons count rate due to the beam depolarization.

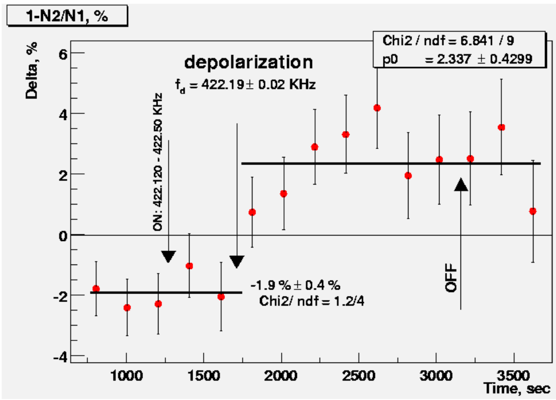

Figure3: Intra-beam scattering count rate jump.

The error of the beam energy definition obtained in the test run is ≈ 30 keV ($\Delta E/E \approx 2\times10^{-5}$). The achieved maximum peak luminosity $L = 4.7 \times 10^{29}$ $cm^{-2}\,s^{-1}$ corresponds to ξ_Y = 0.037 (the 1×1 bunch mode with 2.2 mA per bunch).

3 LUMINOSITY INCREASING

There are two gradient wigglers (GW) and two dipole wigglers (DW) at the VEPP-4M storage ring. Special efforts were undertaken to study the possibility of luminosity enhancement by these wigglers.

3.1 Quadrupole wigglers

VEPP-4M has relatively large horizontal dispersion at the Interaction Point (IP), so the horizontal beam size at the IP is mainly defined by the energy spread. The ratio between synchrotron and betatron horizontal beam size (monochromatization factor) is equal to λ = 1.8 in the nominal operation mode. However, at low energy we can vary this parameter by the GWs, which can redistribute damping decrements between the horizontal and longitudinal planes. Controlling the GWs strength and VEPP-4M lattice we can change λ within a rather wide range (from ~ 1 to 4). Analytical studies [6] have shown that the beam-beam effects are most dangerous for $\lambda \approx 1$. In this case all three degrees of freedom of particle motion are coupled and synchro-betatron resonances become very strong. On the contrary, when $\lambda >> 1$, the particle horizontal coordinate at the IP practically does not depend on the betatron motion, and the beam behaviour becomes almost (quasi) two-dimensional. Width of horizontal and coupled synchro-betatron resonances falls down with the increasing of λ (it is not so for the mere vertical and synchrotron resonances).

Additionally, redistribution of the damping decrements by the GWs provides:

- suppression of high-order non-linear resonances by increasing of the horizontal betatron damping,
- reduction of the horizontal betatron emittance (hence, the dynamic aperture becomes larger in units of rms beam size).
- reduction of the horizontal beam-beam parameter ξ_X, since the total horizontal beam size at the IP increases.

The later allows increasing bunch intensity, keeping ξ_X constant. Experimental results show that for $\lambda \approx 3$ the maximum bunch current obtained is around 2 mA, which corresponds to $\xi_X \approx 0.02$. For the nominal operation mode ($\lambda \approx 1.8$) such current can not be reached because in this case ξ_X = 0.032, which is well above the beam-beam limit.

3.2 Dipole wigglers

Two DWs with the maximum field of 1.8 T provide strong radiation damping against different instabilities and increase beam size and beam-beam current limit.

A numerical simulation of the beam-beam interaction with the LIFETRACK code [5] shows that with the help of DWs we can reach the luminosity $L \approx 10^{30}$ $cm^{-2}s^{-1}$ at the 1×1 mode for a 1.5 GeV energy.

Table 2: VEPP-4M luminosity (LIFETRACK) (ξ_X = 0.015, ξ_Y = 0.03)

Wigglers	Current (mA)	L_{max} ($cm^{-2}s^{-1}$)
Off	1	1.8×10^{29}
On	5	1.1×10^{30}

Table 2 lists the simulation results while the experimental ones are shown in Table 3.

Table 3: VEPP-4M luminosity (experiment)

Wigglers	Current (mA)	L_{max} ($cm^{-2}s^{-1}$)
Off	1.5	1.6×10^{29}
On	3.2	0.7×10^{30}

The measured data with the DWs switching-on correspond to the vertical beam-beam parameter ξ_Y = 0.046. However, the experiments show that in spite of the theoretical prediction the maximum possible emittance increasing by the DWs (4 times) does not correspond to the maximum luminosity because in this case the beam lifetime reduces drastically. One of the possible explanations that due to the combined effects of machine non-linearity (strong chromatic sextupoles), the wigglers and beam-beam non-linearity, the dynamic aperture becomes insufficient for reliable operation.

3.3 Dynamic aperture study

Study of the non-linear beam dynamics was already performed at VEPP-4M several years ago [6]. Since that time, two final focus quadrupoles were replaced by the new ones with improved gradient quality. Besides, the working betatron tune point was moved from (8.62, 7.57) to (8.55,7.60). These two factors yielded a significant increase of the horizontal border of stable motion (two times). However, when two dipole wigglers are used to enlarge the beam phase volume, the horizontal aperture shrinks.

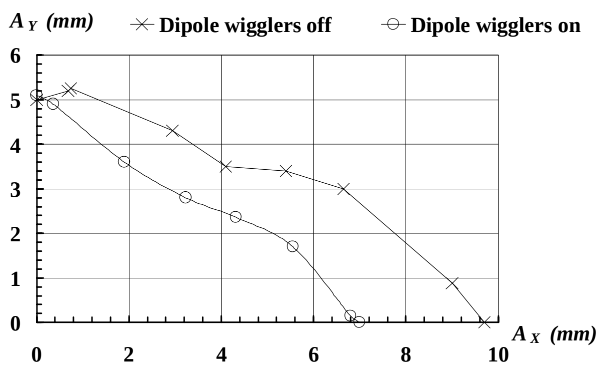

Figure 4: VEPP-4M DA the SRP3-BPM (β_X=4 m, β_Y=13 m).

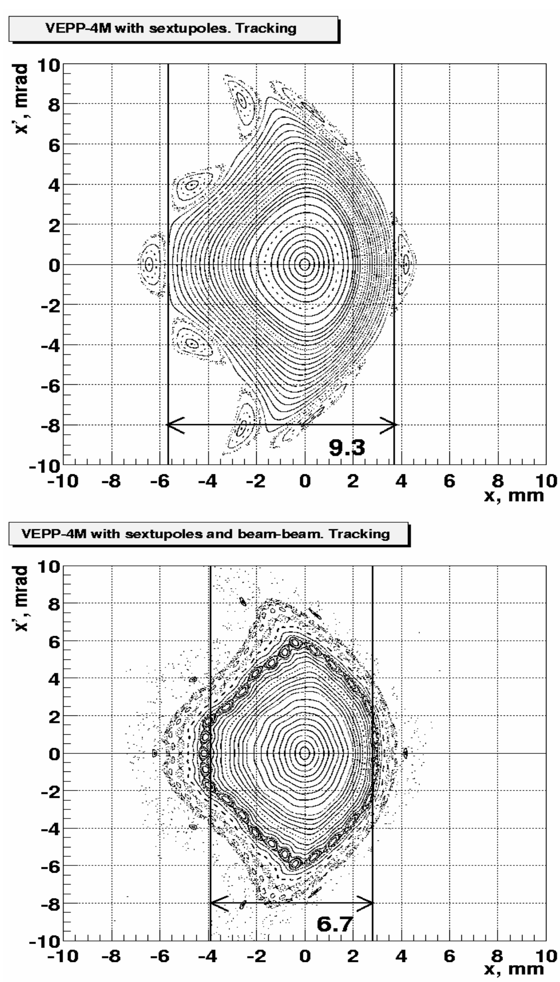

Figure5: Dynamic aperture shrinking due to the beam-beam force. Chromatic sextupoles – upper plot, sextupoles+beam-beam – lower plot.

At an energy of 1.5 GeV, two 1.8 T dipole wigglers provide a strong distortion of the beam motion (especially vertical). At their maximum field the linear tune shift is $\Delta Q_Y \approx 0.13$ and $\Delta Q_X \approx 0.02$.

The vertical aperture in Fig. 4 is not changed due to the wigglers switching-on/off because it is limited by mechanical factors.

One more factor that can reduce the original dynamic aperture is non-linear beam-beam force.

A crude computer code taking into account the realistic distribution of chromatic sextupoles, non-linear imperfections and beam-beam kick (Erskine-Bassetti formalism) shows that combined influence of the high-order sextupole and beam-beam resonances provide widening of the stochastic layer and dynamic aperture reduction (see Fig.5). The work on the improving of the tracking code to study mutual non-linear effects of machine and beam-beam interaction is in progress.

The linear wiggler influence, including the tune matching and the beta-function recovering (inside a 15 % accuracy), are compensated by three pairs of quadrupoles in the experimental straight. However, non-linear components of the wiggler field together with the fringe fields yield a significant reduction of the dynamic aperture (by approximately 30 %) as Fig.4 demonstrates.

4 TECHNICAL PROBLEMS

To calibrate the beam energy with high accuracy, rather tough requirements for stability of VEPP-4M parameters have to be applied. For instance, a long-term relative stability of the dipole magnetic field should be better than 5×10^{-6}. Besides, magnetic field imperfections can destroy beam polarization with the characteristic time τ_r. Estimation shows that for the τ lepton threshold energy with vertical COD rms value ~ 100 μm, the spin decay time for VEPP-4M is around τ_r ~ 30 min. Since depolarization rate depends strongly on the spin resonance tune: $\tau_p / \tau_r \propto (\nu_s\text{-}k)^{-4}$ (at E = 1777 GeV we have $\nu_s = 4.032$), magnetic imperfections and magnets misalignment can significantly limit the energy calibration time. These facts make us pay serious attention to the different aspects of machine stability (power supplies, temperature, geodetic alignment, etc.).

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