STUDY OF THE ENERGY STABILITY IN THE VEPP-4M STORAGE RING

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Abstract

The closest plan of the experiments on the VEPP-4M collider is a high precession mass measurements of J/ψ, ψ'-resonances and τ lepton. Therefore this study of the beam energy stability has been done. This report presents results of the energy stability measurements with respect to the temperature changes, hysteresis cycle, closed orbit distortions, drift and noise in various magnetic elements power supplies. The beam energy is measured by the resonance depolarization technique. The obtained accuracy in beam energy measurements is $\leq 10^{-5}$.

1 INTRODUCTION

The new cycle of precise mass measurements of J/ψ and ψ' mesons has been done at the VEPP-4M facility. The energy of the accelerator was calibrated by the resonant depolarization technique [1, 2]. During the accomplishment of such experiments there is not only a demand for high absolute definition of the energy but its high stability (better than 10^{-5}).This work shows analysis of the main sources for energy error like drift of the magnetic field in different elements, orbit distortions, temperature changes etc. The experimental possibility of precise energy calibration allows to examine these sources and to make necessary adaptations for improvement of the energy stability. The same investigations has been done at the LEP facility [3], where they have found an influence of the moon tide, at the VEPP-2M facility, where they organized a feed back system for the energy stabilization [4] etc. We need to note that high requirements on the energy stability exist at storage ring based synchrotron radiation sources in some experiments also.

2 DESCRIPTION OF THE VEPP-4M FACILITY

The storage ring VEPP-4M is a modernization of VEPP-4 facility. The magnetic lattice of the VEPP-4M consists of two arcs, straight section used for injection system, RF cavities and experimental section [5]. The former is not actually straight, there are bending magnets, with low deflection angle, which are spectrometers for the electrons and positrons lost from the beam because of two photon events. Table 1 presents some parameters of the VEPP-4M.

Table 1: The main parameters of the VEPP-4M.

Circumference	366.6 m
Momentum compaction factor	0.0167
Betatron frequencies (x,z)	8.5415 7.5782
E(J/ψ)	1548.44 MeV

The beam energy is defined by the integral of the magnetic field along the equilibrium orbit. This field is produced by the periodical magnetic cells of the arcs with the total bending angle of 171 degrees and by the 6 magnets of the experimental area with bending angles of 18 degrees.

The periodical magnetic cell consist of two magnets, each of them has an area of homogeneous field and F- or D- sections, the field of that is about half of the field in the flat part. There is a gradient correction in the focusing section, which changes the field also. There are two non standard periodical magnetic cells in the middle of the arcs. They consist of quadrupole lenses and magnets with homogeneous field. All periodical magnetic cells are connected in series to the one power supply. The gradient correction is connected in series also. The sextupole coils placed in the magnets of the arcs are used for natural chromaticity compensation. The change of the field gradient in the focusing sections and the power of sextupole lenses of the arcs changes the energy of the storage ring. For compensation of such energy changes during the betatron frequencies and chromaticity tuning we use special algorithms in the control system. For symmetry preservation of the storage ring the bending magnets of the experimental area are electrically connected in pairs to the different power supplies. Thus there are 9 independent power supplies (under 100 kWt) which change the magnetic field on the equilibrium orbit and therefore define the particle energy besides the main power supply of the arcs. There are 60 radial correctors, which also have an influence to the particle energy.

There are 5 NMR sensors used for control of the magnetic field. These sensors are placed in magnets with homogeneous field. One of them is placed in the reference magnet, which is a copy of the main bending magnet and connected in series to the same power supply. This sensor is a primary field control in the arcs.

3 THE MAIN FACTORS, CAUSING ENERGY DRIFT

1. *Instability of the revolution frequency.* It is known that given energy stability requires stability of the revolution frequency $1/\alpha$ (α is a momentum compaction

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factor) times higher than stability of the field. The RF system of the VEPP-4M has revolution frequency stability 10^{-8} that gives energy ripple less than 10^{-6}.

2. *Displacement of the different magnetic elements or changing of the circumference of the VEPP-4M ring.* The observations show that changing of the circumference has a season depending character. The maximum relative circumference change is 10^{-5}, that gives change of the energy $6 \cdot 10^{-4}$. The estimations made show that maximum daily energy shift with respect to temperature delays of season changing is about $6 \cdot 10^{-6}$. There are also possible displacements of the elements because of fast (daily) temperature changing.
3. *Ripple of the field in the magnetic elements.* This item is explained below.

4 THE INFLUENCE OF THE FIELD ON THE ENERGY

4.1 The calculations

Obviously, the influence of the particular element on the energy is defined by deflecting angle and optical properties of the storage ring. Let us define the value of that influence. The change of the deflecting angle of the magnet or corrector $\Delta\theta_i$ with the fixed energy causes closed orbit distortion and changes the length of the orbit [6, 7]:

$$\Delta L = \Delta\theta_i D_i \ , \tag{1}$$

where D_i is a value of the dispersion function in that element. The revolution frequency is constant in the accelerator and thus a circumference too. Paying attention to the relation between the closed orbit length change and change of the energy:

$$\frac{\Delta E}{E} = -\frac{1}{\alpha}\frac{\Delta L}{L} \tag{2}$$

it is not complicated to obtain the influence of the deflecting angle change on the energy [8]:

$$\frac{\Delta E}{E} = -\frac{1}{\alpha}\frac{\Delta\theta_i}{L}D_i \ . \tag{3}$$

Hence, the relative change of the magnetic field $\Delta H/H$ in the magnet with the bending angle θ_i will cause the relative energy change:

$$\frac{\Delta E}{E} = -\frac{1}{\alpha}\frac{\Delta H}{H}\frac{\theta_i}{L}D_i \ . \tag{4}$$

Using random orbit distortion $\langle\Delta x\rangle_{rms}$ and averaging over the random betatron phases of the closed orbit we obtain:

$$\left(\frac{\Delta E}{E}\right)_{rms} \simeq \langle\Delta x\rangle_{rms}\,\frac{2\sqrt{2}\sin\pi\nu}{\alpha L}\,\frac{\bar{D}_x}{\bar{\beta}_x} \ . \tag{5}$$

Making an evaluation one can see that orbit disturbance of 100 μm relates to the energy shift of $5 \cdot 10^{-6}$.

4.2 The measurements

To verify equation 3 we conducted experiments introducing the known orbit angle in the different elements:

1. correctors, situated in positions with different sign of dispersion function,
2. a pair of bending magnets of the experimental area.

The results are shown in Table 2. A good agreement has been found between the measurements and calculations in case of small orbit distortions. We need to note, that sign of energy change depends on sign of the dispersion function in the corrector.

Table 2: Comparison between predicted and measured energy shift because of orbit distortions.

Element	D_i, cm	$\Delta\theta_i$ mrad	Energy shift, ppm	
			theory	measurements
corrector NRX3	80	±0.5	∓66	∓46
corrector NTX1	-31	±0.5	±24	±25
magnet SEM	120	±0.24	∓46	±39

The goal of the different experiments was to study how the closed orbit bump influence on the energy. For simplicity, the bump was made by two correctors of the same sign, placed on the half wave of the betatron oscillations. We compared two bumps — one in arc, the other in straight section. In case of the arc, the local orbit length change is proportional to the value of the bump and compensated in the remaining part of the ring. In the straight section the length of the local orbit is increased only in second order, the first one disappeared because of absence sign alteration of the dispersion function. Therefore in the former case, the stretching of the orbit length is negligible. Hence, the bump in the arc should change the particle energy, but in the straight section should not. Table 3 presents results of that experiment. From the results of this measurements one can see that radial orbit distortions can significantly change the particle energy. The influence of the bump with the same amplitude in the arc is much bigger than in the straight section. Therefore there are high demands on the orbit stability during the precise experiments. In our mass measurement

Table 3: Comparison between predicted and measured energy shift because of orbit bump.

Location of the bump	Amplitude	Energy shift, ppm	
		theory	measurements
ring	±2.6 mm	∓129	∓122
straight section	±2.2 mm	−2	−2

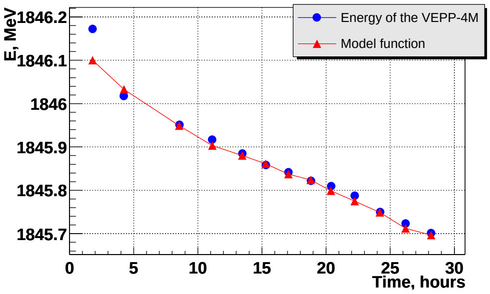

Figure 1: Temperature dependent energy drift.

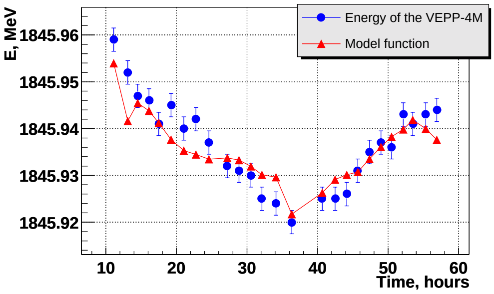

Figure 2: Two days of energy measurements in March 2002.

experiments the requirement on the orbit stability between the energy calibrations was less than $100\ \mu m$. The influence of the vertical orbit distortions has same second order term as the bump in the straight section.

5 THE INFLUENCE OF NON-STATIONARY PROCESSES

5.1 *Relaxation of the magnet field*

All VEPP-4M elements of the magnetic system are made of a solid piece of iron. The measurements of the magnetic field showed that there are two characteristic times of the transitional process. The first one is fast ($3\tau \simeq 30$ min), caused by eddy currents. The second one is slow ($3\tau \simeq 4$ hours), which might be caused by delay of the domain growth. The hysteresis effect of the magnetic elements plays an important role. The hysteresis value depends on the type of the magnet, the value of the induction in the iron. Therefore, before starting the work or after any interruption we do the standard magnetization cycles. The desirable energy is set by decreasing the value of the field starting from the maximum one. After these cycles in 4-5 hours the energy is restored with an accuracy of $2 \cdot 10^{-6}$.

5.2 *The temperature influence*

The other reason of non-stationary processes is a temperature drift of cooling water and air. During the work on the low energy the magnets of the arcs were not cooled down, therefore the time of temperature stabilization was about two days. The final temperature depends on the temperature of the air. The coils of the remaining magnets were water cooled. The time of temperature stabilization was lower and the final temperature depends on the temperature of the water and air.

There was found a significant energy shift with respect to the temperature of the arcs magnets in the experiment. Figure 1 shows the results of the measurements after the magnetic system was switched on. Figure 2 shows two days energy drift in stationary conditions. The analysis of those plots allowed us to build a model formula of energy dependence on temperature of the magnetic elements:

$$\frac{E}{E_0} = 1 - (41 \cdot T_1 + 0.9 \cdot T_2 - 7 \cdot T_3) \cdot 10^{-6}\ , \qquad (6)$$

where T_1 , T_2 , T_3 -temperature of different elements. The maximum temperature coefficient belongs to the magnets of the arcs and its value is 41 ppm. This large value of that coefficient is explained by peculiarities of the arc magnet design, thus the changes of the magnet gap and length do not compensate each other, by the change of the ring radius and by the change of the magnetic permeability. The comparison of the experimental and model curve is shown in the Figures 1,2. A sufficient agreement has been found. The usage of this model allowed us to evaluate the energy shift between the calibrations by the resonant depolarization technique.

6 CONCLUSION

The presented above investigations allowed us to calculate the shift of the energy because of the orbit bump caused by the change of the field in different magnets. The strong influence of the magnet temperature was shown. However, the temperature dependence is not explained by simple change of the magnet sizes.

7 REFERENCES

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