MATCHING AND USE OF DIPOLE WIGGLERS IN THE COLLIDER VEPP-4M TO CONTROL BEAM PARAMETERS AT LOW ENERGY RANGE OF OPERATION

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Abstract

Experimental and calculation data on matching and using the dipole wigglers with the field up to 2 Tesla to control beam sizes, radiation damping decrements and threshold beam currents at the low energy range (1÷1.8 GeV) of the VEPP-4M operation are discussed. This energy range is of interest to measure the total cross-section of annihilation e^+e^- into hadrons but is not typical of the given machine, so the investigations, in particular, regarding the use of wigglers, are being conducted in order to achieve reasonable luminosity.

INTRODUCTION

A start has been made in physical experiments with the new detector KEDR at the modified collider VEPP-4M [1]. In particular, possibilities to obtain reasonable luminosity in the energy range between ϕ-meson and J/Ψ-particle, which is of interest to measure the total cross-section of annihilation e^+e^- into hadrons, are being studied. To control beam parameters in these experiments two "warm" three-pole wigglers (dipole wigglers or DWs) with the length of about 1 m and the field up to 2 Tesla, installed symmetrically to the interaction point (I.P.) at the non zero dispersion sections of the experimental area, are used. They considerably disturb beam focussing and the closed orbit with lowering the energy so it was taken to develop a special matching procedure. The main magnetic structure of the VEPP-4M storage ring is originally based on the 22 GeV proton synchrotron scheme with a combined function lattice. By this reason we normally apply two quadrupole-dipole wigglers (gradient wigglers or GWs) installed in the technical section to overcome radial antidamping. The influence of our DWs on damping partition may be of the same order and therefore was needed to be investigated. Study of the DWs efficiency to manipulate the longitudinal and transverse sizes is very important if we have the aim to increase the luminosity and the threshold current determined by the TMC instability. Touschek effect should be also taken into account since it sufficiently affects the beam properties in the energy range under consideration.

1. MATCHING

The disturbances of focussing in a storage ring with the same N dipole wigglers per each super-period can be described by the modifying matrix of transverse phase space transformation over the super-period in the following form: $T'=T+\Delta T$. Here T is the transfer matrix in the case without wigglers and the perturbation ΔT may be expressed in the "thin-lens" approximation for a focussing influence of wiggler as a polynomial of degree N in the variable $h=L_W(H_W/HR)^2$ with the coefficients C_m as 4×4 matrices:

$$\Delta T = \sum_{m=1}^{N} C_m h^m$$

(H_W is field magnitude of the dipole wiggler of length L_W; HR is the magnetic rigidity). The general view of ΔT is determined by the features of a magnetic structure and the property of dipole wigglers to give contribution into a focussing mainly for vertical (Z) direction of particle motion and to be a straight section for X-direction. One can correct the disturbances by changing gradient (G) in some optimal set of quadrupole lenses. Note , that such an optimization

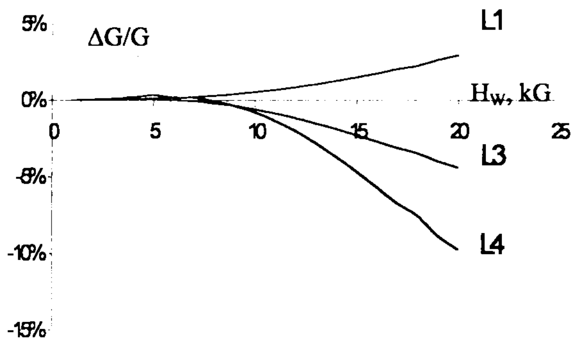

Fig.1. Relative tunes of gradient in three pairs of lenses from the experimental section under changing the dipole wigglers field (E=1 GeV).

of a magnetic structure inevitably concerns both transverse particle motion degrees of freedom.

In the case of VEPP-4M N=2. An optimal set of quadrupoles has been found in three pairs of lenses (L1 from a low-beta insert, L3 and L4) in the experimental section. The lenses of each pair are symmetrical in position about the I.P. and have the same gradient. More number of lenses causes degeneracy of the optimization problem solution in our case. The optimization problem is attacked in two stages. Firstly, the functional determined through the beta-function values and their derivatives at I.P. as well as the maximum beta values in the low-beta insertion is minimized. In accordance with the given determination of ΔT, the numerical solutions obtained (see Fig.1) fit in good accuracy the expansion $G \approx G_0\ (1+p\cdot h+q\cdot h^2)$. Here G_0 is a gradient value in the case of $H_W=0$; p and q are the coefficients. Secondly, we correct the betatron tune shifts caused by the joint action of the DWs and the mentioned system of lenses, using a general correction of tunes in the semirings. In particular, the necessary tune corrections are $\Delta Q_z \approx 0.3$ and $\Delta Q_x \approx 0.05$ at $E=1$ GeV , $H_W=1.8$ Tesla. The matching procedure is computer controlled and allows simultaneously to change the energy in a wide range, to turn on/off the DWs and to correct closed orbit without noticeable losses of stored particles .

2. DAMPING AND SIZES

To describe dipole wiggler influence on the longitudinal damping partition number, the latter can be written as $J_s=2+(I_4+I_4^W)/(I_2+I_2^W)$. Here I_2 and I_4 are the known synchrotron radiation integrals [2] in the machine without DWs. The terms labelled W describe the contributions of the DWs [3]. In conventional conditions of the VEPP-4M operation $I_2^W=I_4^W=0$, $I_4 \approx 0$ and $J_s \approx 2$, $J_x \approx 1$. The damping partition is controlled through setting a current $I_{GW} \neq 0$ in coils of gradient wigglers. The DWs change partitions numbers and reduce damping times. When lowering the energy down to 1 GeV the term I_2^W may exceed in several times the term I_2 if the DWs field is sufficiently large. Besides, the ratio I_4^W/I_2^W determined by a self dispersion in the DWs is negligible. Hence $J_s \approx 2+I_4/I_2^W$. As this takes a place, according to calculations , even turning off the GWs ($I_4 \to 0$) can not cause antidamping in radial motion, starting with some value of the DWs field (see Fig.2). Measurements of the radial and

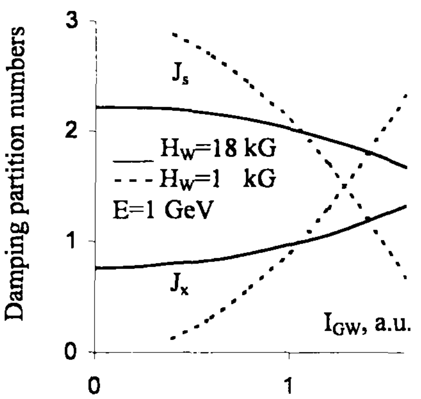

Fig.2. Damping partition numbers vs. the GWs current at two values of the DWs field.

longitudinal beam sizes performed in correspondent conditions prove the calculated result. As shown in Fig.3, below the threshold GWs current $I_{GW} \approx 200$ A the 1 GeV electron beam blows up along a radius and do not "live" at zero DWs current ($I_W=0$). By contrast, the beam is stable with decreasing I_{GW} down to zero if

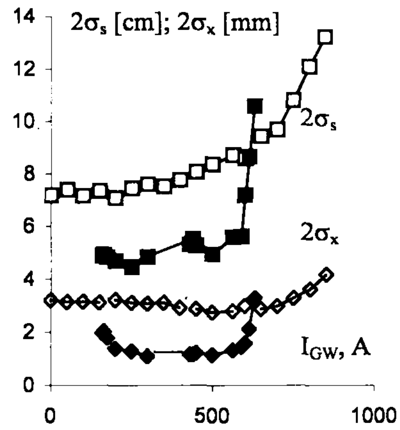

Fig.3. Measured dependence of the radial ($2\sigma_x$) and longitudinal ($2\sigma_s$) beam sizes upon the current of gradient wigglers at E=1 GeV with $I_W=1800$ A (light points) and $I_W=0$ (solid points).

$I_W=1800$ A ($H_W \approx 17$ kGs). Thereby it has been demonstrated that DWs can provide per se the radiation damping of radial oscillations in the storage ring with a combined function lattice.

If to take into consideration radiation effects only, it can be evaluated that the VEPP-4M DWs with the maximal field at E=1 GeV increase the radiation decrements in 5 times, the radial emittance in more than 20 times and the energy spread in around 3 times. Influence of Touschek effect significantly changes these ratios in respect to emittance and energy spread. To underline it we present the Fig.4 where the energy spread versus energy curves measured and calculated at $H_W=0$ are shown. Here experimental

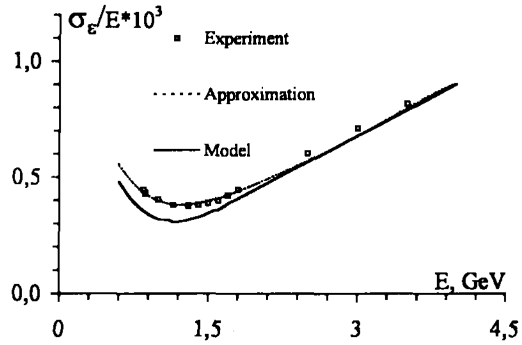

Fig.4. Energy dependence of energy spread (the beam current is 0.1 mA).

data have been obtained by measurement of a longitudinal beam size at a synchrotron frequency kept constant. The experimental dependence can be approximated by the function $\sigma_E/E=(a/E^2+b\cdot E^2)^{1/2}$. The solid curve presents the results of multiple Touschek processes self-consistent model calculation. On Fig.5, a measured radial beam size versus the

DW current is given for some set of values of energy (the DWs current I_W=2 kA corresponds to the field about of 1.8 Tesla). The dotted curve on the plot is calculated in view of Tousckek effect for the case of energy E=1 GeV. As shown in Fig.3 and Fig.5 the use

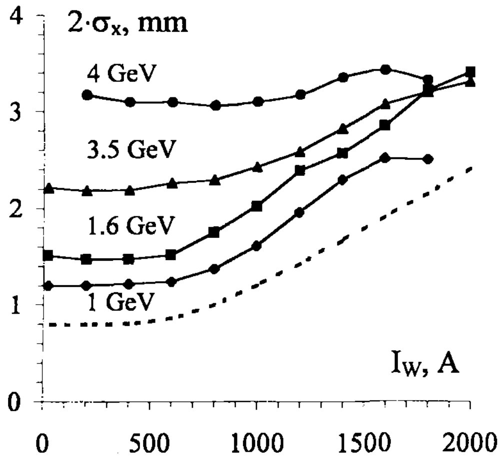

Fig.5. Manipulation of the radial size with help of dipole wigglers.

of DWs with the maximum field at E=1 GeV allows to increase sufficiently the absolute values of beam energy spread and sizes although the relative changes of these parameters are less by a factor about of one and half due to Touschek effect.

3. TMC INSTABILITY

Reactive component of the longitudinal impedance of the VEPP-4M is inductive and results in bunch lengthening. Value of the normalised impedance is $|Z_{\|}/n|[\Omega]\cong$ $0.75\cdot\sigma_s$[cm]. TMC (transverse mode coupling) instability takes a place in the vertical plane. This effect is characterised by a large coherent shift of betatron frequency and by threshold beam current.

In frameworks of the two particles model one can use the expression for coherent tune shift [4]

$$\Delta Q_c = \frac{\mathrm{Im}\,\langle Z_{\perp}\beta\rangle \hat{I}}{8\pi(E/c)},$$

where $Im\langle Z_{\perp}\beta\rangle$ is reactive component of the transverse impedance averaged with the β weight factor; β is a beta –function at the impedance location; $\hat{I}$ is amplitude value of the beam current, expressed through the average current $\bar{I}$ and the circumference Π as $\hat{I}=(2\pi)^{-1/2}\Pi\cdot\bar{I}\cdot\sigma_s^{-1}$. The measured value of $\langle Z_{\perp}\beta\rangle$ is about of 25 MΩ. The current threshold is reached when $\Delta Q_c\geq 0.8\cdot\nu_s$ (ν_s is synchrotron frequency).

The VEPP-4M average current threshold can be approximated by the expression where a bunch lengthening is taken into account:

$$\bar{I}_{th}[A]\approx 6.8(\sigma_\varepsilon^{\,3}+\sigma_\varepsilon\nu_s\cdot 2.8\cdot 10^{-5})^{1/3}\cdot E[GeV].$$

Two ways to enhance the threshold current can be seen from this formula, namely, increasing the synchrotron frequency and providing a large beam energy spread σ_ε. The availability of two dipole wigglers furnishes such an opportunity. For instance, $\bar{I}_{th}$=7 mA (E=1.8 GeV) at H_W=0. Turning on the field H_W=2 Tesla increases $\bar{I}_{th}$ at least by factor 1.5 ($\bar{I}_{th}$=11 mA).

4. LUMINOSITY AT LOW ENERGY

Experiments on obtaining reasonable luminosity in the region 1-1.8 GeV were carried out for a set of energy values with a maximal beam current achievable for these energy values. Theoretical dependence of maximum luminosity on energy in the regime of 2×2 beams under assumption that the magnetic structure is kept constant (including a relative field of dipole wigglers with an absolute value 1.8 Tesla at 1.8 GeV) is illustrated by the Fig.6 [1]. In the experiments the wigglers field was being optimized. Generalized experimental data are close to the E^4-dependence in Fig.6 except the 1 GeV point where the luminosity value limitation seems to occur due to neither the

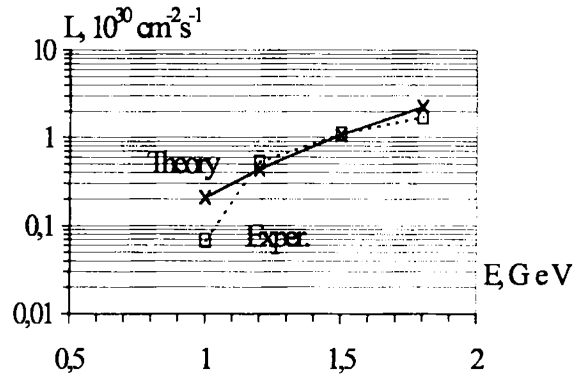

Fig.6. Luminosity versus energy.

beam-beam effects nor TMC instability. Probably, the reason is connected with a self excitation of vertical betatron oscillations being observed in a single beam at work range beam currents (1-2 mA and above). So the study at this energy should be continued.

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