ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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VEPP-3 DEDICATED STRAIGHT SECTION FOR OK OPERATION

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ABSTRACT

Late in 1985 the decision was made to up-date to storage ring VEPP-3 with a view to create an additional straight section (bypass) dedicated for the optical klystron (OK) operation.

1. INTRODUCTION

The design of the bypass and new magnetic system for the OK was completed by the end 1986. In March of 1988 the bypass was mounted on VEPP-3, the circulating electron beam was captured and spontaneous undulator radiation from the OK was generated in April, the mirrors of the optical cavity were installed in May. On June the lasing was achieved and the continuous tuning of the wavelength from 5800 to 6900 Å with the spectral bandwidth less then 0.6 Å was demonstrated. So far generation also was obtained in the 3800—4500 Å and 2400—2700 Å ranges [7].

2. BRIEF DESCRIPTION OF THE STORAGE RING VEPP-3

The storage ring VEPP-3 is a strong focusing racetrack consisting of two half-rings and two straight sections (see Fig. 1), each containing four identical quadrupole doublets. Now all the doublets are powered in series by one power supply unit. The doublets are arranged and the gradients in them are chosen in such a way that the matrices describing vertical and horizontal betatron oscillations in the sections are unit. Each half-ring comprises eight superperiods designed as the 22.5° magnets. Inside a magnet there are two sections with homogeneous magnetic field and the other two with different-sign field index, i. e. the FODO structure is realized. The field-index sections are designed as the half-quadrupoles. The circumference of the storage ring is 74.4 m and the straight section is 12 m long each. In superperiod, the advance of betatron phases (in vertical and horizontal directions) are close to $0.2\times2\pi$, while the corresponding betatron frequencies are close to $16\times0.2+2=5.2$ (the phase advance on the straight section is 2π). Varying the field in half-quadrupoles by means with correcting windings, we can vary betatron frequencies. The compaction factor is 0.06. The RF system consists of two accelerating cavities, on the 2nd and 18th harmonics of revolution frequency (4.03 MHz).

The maximum voltage is 14 kV at the first harmonic cavity (it is limited by a heating of ceramic capacitors positioned in the cavity) and 700 kV at the 18th-harmonic cavity. Injection to the storage ring is performed at 350 MeV with the 18th-harmonic cavity off. A large wavelength of the accelerating voltage (37.2 m) and a short (about 40 ns) inflector pulse make it possible to use a one-turn multiple injection in the vertical direction with a delay in time, of the inflector pulse relative to the moment of flight through it of the stored beam. In this case, only the injected portion of electrons acquire coherent longitudinal oscillations and this allows one to have a small vertical aperture (24 mm in half-rings) without any loss in the injection efficiency.

In the course of updating the 22.5° magnets, the nearest to the experimental straight section of the storage ring (where the previous version of the OK was located) were replaced by C-shaped magnets power supplied by a separate current source. For bypass works these magnets are switched off.

3. MAGNETIC AND VACUUM SYSTEMS OF THE BYPASS

The bypass is assumed to satisfy the following requirements and restrictions:

a) the working energy corresponds to the injection energy (350 MeV);

b) the zero transverse dispersion (η-function) throughout the straight section;

c) the overall dimensions are limited by the VEPP-3 area, whereas the radiation from OK should go to a bunker for SR works;

d) the distance between the experimental straight section and bypass axes are bounded below by horizontal overall dimensions of the components of their magnetic systems;

e) in the operating modes with and without bypass the tuning range of RF generator and resonator frequencies sets an upper bound on the difference in equilibrium orbit lengths;

f) the magnetic bypass components should match β-functions in the half-rings to optimal β-functions of the OK and improve the electron beam parameters with care for as large free space as possible in the centre of the bypass to install the magnetic system of the OK.

The bypass magnetic system is schematically shown in Fig. 1. Its axis is 0.65 m distant from the straight section axis. The field in 22.5° bending magnets of the bypass is 14 kG. The pairs of quadrupole lenses positioned between these magnets and storage ring half-rings are intended to match η-function to zero in bypass. The remaining four pairs match β-functions in the storage ring with optimal β-functions in OK (see Fig. 2). To increase the vertical emittance and betatron and synchrotron oscillation damping decrements, a three-pole wiggler with horizontal magnetic field (up to 18 kG) was installed at the bypass.

The vacuum chamber is made of stainless steel. Pumping out is done by eleven units comprising both magnetic discharge and titanium sorption pumps. Seven pickup stations monitor the position of the equilibrium orbit. To evacuate the residual gas ions, the negative constant voltage (300 V) is applied to pickup electrodes.

4. MAGNETIC SYSTEM OF OK

As in the our previous version [1—4], the magnetic system of FEL consists of two undulators and a three-pole wiggler between them (buncher) i. e. it is identical to the OK design described in [5, 6]. In view of the design considerations, 7.8 m are left for the magnetic system of the OK. The electromagnetic buncher (of the earlier version of OK-3), a pickup station, a pumping-out unit and a vertical corrector were positioned between the undulators and hence each undulator may be placed on a 3.4 m free space. To use mirrors with standard reflecting covering, a 0.63 μm wavelength of a helium-neon laser was taken as the reference wavelength. In this case

$$\lambda=\frac{\lambda_0}{2\gamma^2}\left(1+\frac{K^2}{2}\right), \quad K=.0934\cdot H_0(\mathrm{kG})\cdot\lambda_0(\mathrm{cm}), \qquad (1)$$

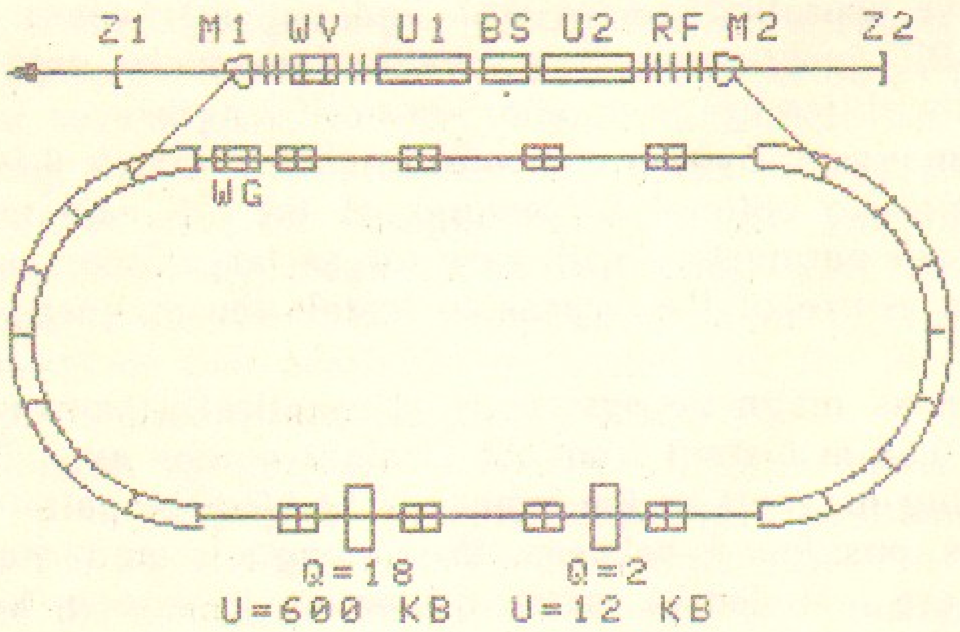

Fig. 1. Layout of VEPP-3 storage ring with the bypass.

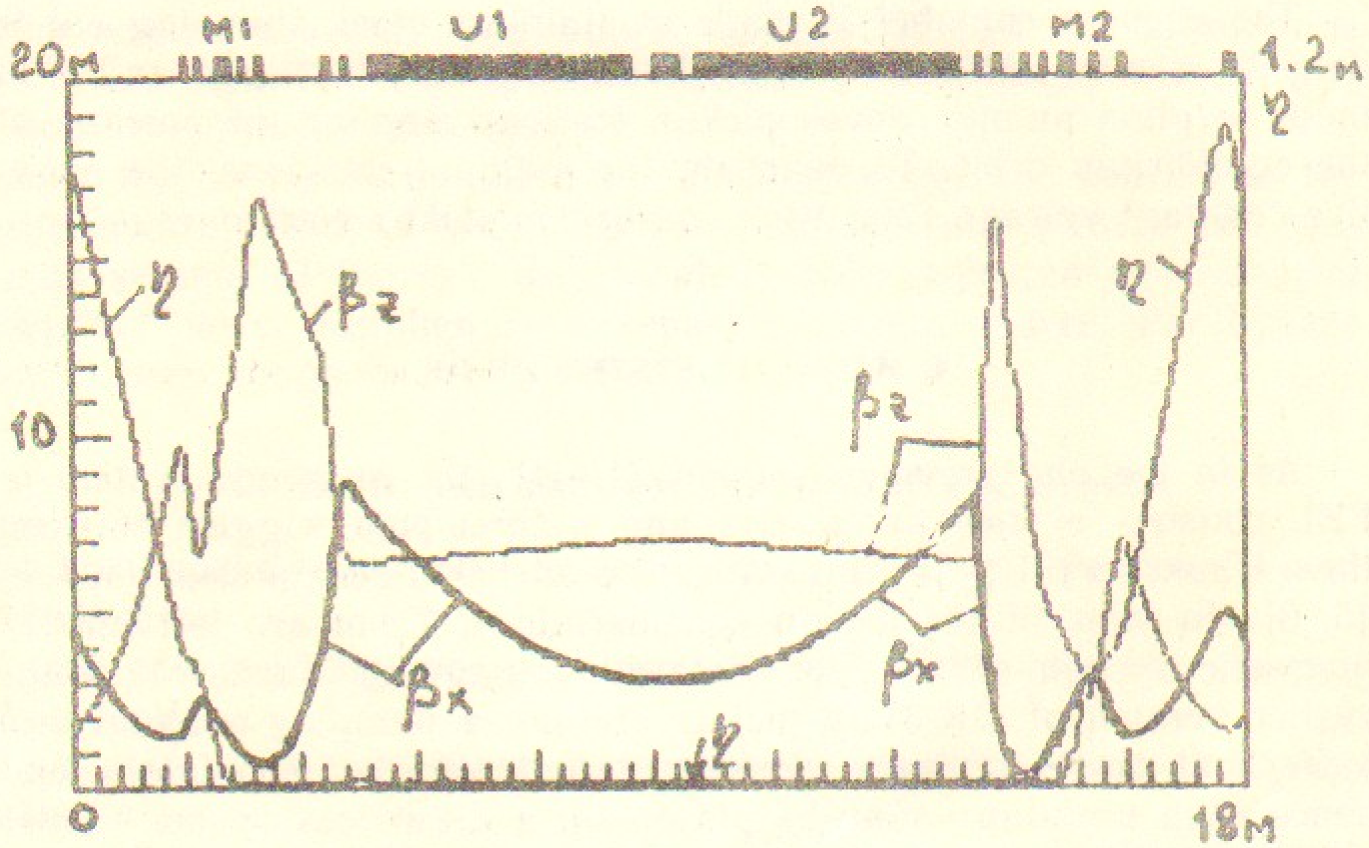

Fig. 2. Optimized β- and η-function in the bypass for operation.

where λ_0 is the undulator period and γ — the relativistic factor. Analysis of possible designs of such long undulators has shown that superconductivity and permanent magnets gives rise to great difficulties in manufacturing and service. In view of this, we developed and manufactured nonsuperconducting electromagnetic undulators [8]. The undulator field is generated by eight periodically-curved water-cooled copper 18×18 mm buses. The parameters of this device are given in the Table below.

Table

Undulator parameters

Length, m	3.4
Period, cm	10
Number of the periods,	33.5
Number of the windings,	8
Bus cross section, mm^2	18×18
Consumed current, kA	2.2
Magnetic gap, cm	2.2
Pole width, cm	9
Maximum magnetic field on the axis, kG	5.3
Consumed power, kW	30

Equation (1) indicates that for work at a wavelength of 0.63 μm it suffices to have a 3.5 kG field, in other words, the undulator period could be less. We have to take into account a few arguments and this leads to such an «overestimated» period. First, the nonlinearity of the vertical focusing of undulator contributes to the non-isochronism of betatron oscillations in inverse proportion to the undulator period. Second, for 3.5 kG field the matched vertical β-function is equal to $\beta_z = 4.9$ m, and the corresponding advance of betatron advance in the magnetic system of the OK is close to thus providing the suppression of the contribution given by the nonlinearity mentioned above to the nonlinear resonances. Third, the consumed power drastically increases with decreasing the period (the current in buses rises but their cross section must be reduced). The vacuum chamber in undulators is a flattened stainless steel tube with 18 mm vertical and 75 mm horizontal apertures. If we take into consideration the fact that in half-rings the equilibrium orbit has 2-3 mm distortions in the vertical direction and in the undulator the orbit is aligned exactly in the median plane, it is clear that such a vertical aperture does not decrease the acceptance of the facility.

The large horizontal aperture ensures both the extraction of undulator radiation on vacuum chamber surfaces in close proximity to pumping units and the fairly high rate of pumping out from the vacuum chamber of the undulator.

5. OPTICAL CAVITY

The optical cavity comprises two mirror, 18.7 m distant from each other. This distance is a one quarter of the circumference for a laser to operate in synchronization mode (i. e. for the light bunch flying in the optical resonator to interact with the electron bunch whenever the latter passes through the OK). The curvature radii of the mirrors are equal and standard (10 m) from manufacturing considerations. The mirrors are positioned on the bypass axis and are equally spaced from the centre of the magnetic system. The confocal parameter of the cavity is easily estimated to be equal to 2.5 m. For 0.63 μm wavelength, the lowest-order of the optical cavity is 0.9 mm in radius at the centre of the cavity and 2.9 mm on the mirrors. The mirrors are placed in small vacuum chambers connected to the bypass chamber by channels. When replacing mirrors, their vacuum chamber are isolated by shutters; we open them again after sufficiently good vacuum is reached in the chambers (without heating). In the channels there are pumping units and radiation receivers located. The residual-gas pressure in the chamber of the front mirror is about $1\cdot10^{-8}$ Torr without the electron beam and about 10^{-7} Torr in the presence of the electron beam. The mirrors are aligned by rotating their vacuum chambers connected to the channels by means of bellows. At the beginning of the run the reflection factors were better than 99.9%.

6. THE WORK WITH ELECTRON BEAM

The circulating electron beam was obtained immediately after the magnetic system of the bypass was switched on. The vacuum chamber was outgassed in the mode of high stored current (up to 0.2 A). Without the negative voltage at the pickup electrodes the ultimate current was lower by a factor of 2-3. After several amperes-hours of the outgassing the vacuum at about 20 mA beam currents became better by one order of magnitude (to 10^{-8} Torr).

The revolution frequency eighteenth-harmonic cavity was switched to rise the peak current. The maximum peak current obtained was about 5 A.

At present the OK works are being performed at currents lower than 30 mA. This is due to the transverse instability of the electron beam, which causes its enlargement. The situation is expected to improve as soon as a wiggler with horizontal magnetic field will be used.

The energy spread σ_E/E and horizontal emittance, the calculation of which was made involving the length and horizontal size of the bunch at low currents, are consistent with expected values, $2.5\cdot10^{-4}$ and $3\cdot10^{-6}$ cm. The vertical size is several times less than the horizontal size and this corresponds to the vertical emittance roughly equal to 10^{-6} cm.

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для работы с оптическим клистроном
на накопителе ВЭПП-3**

Ответственный за выпуск С.Г.Попов

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