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Section I. Existing experiments

THE VEPP-3 STORAGE-RING OPTICAL KLYSTRON: LASING IN THE VISIBLE AND ULTRAVIOLET REGIONS

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Lasing in a wide spectral range (from visible to ultraviolet, 2400–6900 Å) was reached in the optical klystron OK-4 installed on the VEPP-3 storage ring. OK-4 is the first FEL operating in UV.

1. Introduction

The optical klystron was proposed in 1977 by Vinokurov and Skrinsky [1] as a modification of a free electron laser (FEL). It has a much higher gain per pass than a FEL, due to using a special device – a buncher located between two undulators. Experiments with an optical klystron (OK) have been carried out at our Institute since 1979.

In late 1985 it was decided to update the VEPP-3 storage ring. One of the most important tasks of this modernization was to install an additional straight section (bypass) dedicated to OK operation. In March 1988 the bypass was successfully installed on VEPP-3, in April a circulating electron beam was captured and on June 3 lasing was attained and wavelength tunability from 5800 to 6900 Å, with a line width less than 0.6 Å, was achieved. In July and October 1988 lasing in the violet (3750–4600 Å) and ultraviolet (2400–2700 Å) ranges was also obtained [3].

2. A bypass on the VEPP-3

The scheme of the VEPP-3 storage ring with the bypass is shown in fig. 1. The bypass consists of two bending magnets, twelve quadrupoles, a vertical wiggler and an OK magnetic system of 7.8 m length. The bypass focusing system is very flexible and it gives us a possibility to optimize the electron-beam parameters in the OK and to match η- and β-functions with VEPP-3 arcs under different conditions.

3. OK magnetic system

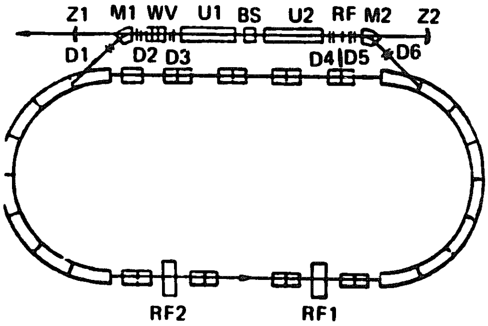

Fig. 1. Layout of the VEPP-3 storage ring with the bypass: M1, M2 – bending magnets; D1–D6 – quadrupole lenses; U1, U2 – undulators; BS – bunching section; WV – vertical wiggler; RF – 1.2 GH_2 passive rf cavity; RF_1 – 8 MH_2 rf cavity ($q = 2$, $U_{\mathrm{m}} = 12$ kV); RF2 – 72 MHz rf cavity ($q = 2$, $U_{\mathrm{m}} = 12$ kV); RF2 – 72 MHz rf cavity ($q = 18$, $U_{\mathrm{m}} = 600$ kV); Z1, Z2 – optical cavity mirrors.

The OK magnetic system comprises two electromagnetic undulators with a buncher (3-pole wiggler) between them. The cross sections of the undulator are schematically shown in fig. 2 and its parameters are given in table 1.

The field in the undulator is excited by eight periodically bent copper buses with holes for water cooling. The buses are commuted on the ends of the undulator.

Each undulator has 68 poles; the ones on both ends are wound by one turn and they have half the magnetic potential. Undulators are installed on the bypass one after another and are bilaterally symmetric about the centre of the section between them. This automatically provides absence of any equilibrium orbit distortion in the storage ring.

The electromagnetic undulators allow a wavelength of fundamental harmonics tunability from 1000 up to 15 000 Å by changing the magnetic field (at 350 MeV fixed energy), i.e. by changing the *K*-factor.

The gain values were measured by comparing with

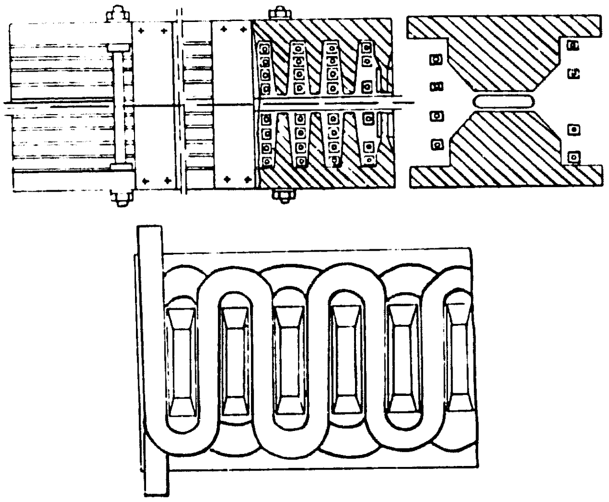

Fig. 2. Cross section of the OK-4 undulator.

the optical cavity losses on the edges of the reflection bands, where lasing was stopped: 10% at 6000 Å, 5.5% at 4000 Å and 3.5% per pass at 2500 Å.

4. Lasing in the OK

When the OK is tuned above threshold, i.e. the OK gain is more than the optical-cavity losses and the revolution frequencies of the electron and light beam are synchronized, the lasing appears on a wavelength where the OK has a maximum gain. Some of the measured spectra are shown in fig. 3.

Table 1
Parameters of the OK-4 undulator

Undulator length [m]	3.4
Number of periods	33.5
Period [cm]	10
Magnetic gap [cm]	2.2
Maximum magnetic field along the axis [kG]	5.3 (5.7)
Pole transverse width [cm]	9
Number of separate buses	8
Cross section of a bus [mm^2]	18×18
Current consumption [kA]	2.2 (3)
Power consumption [kW]	60

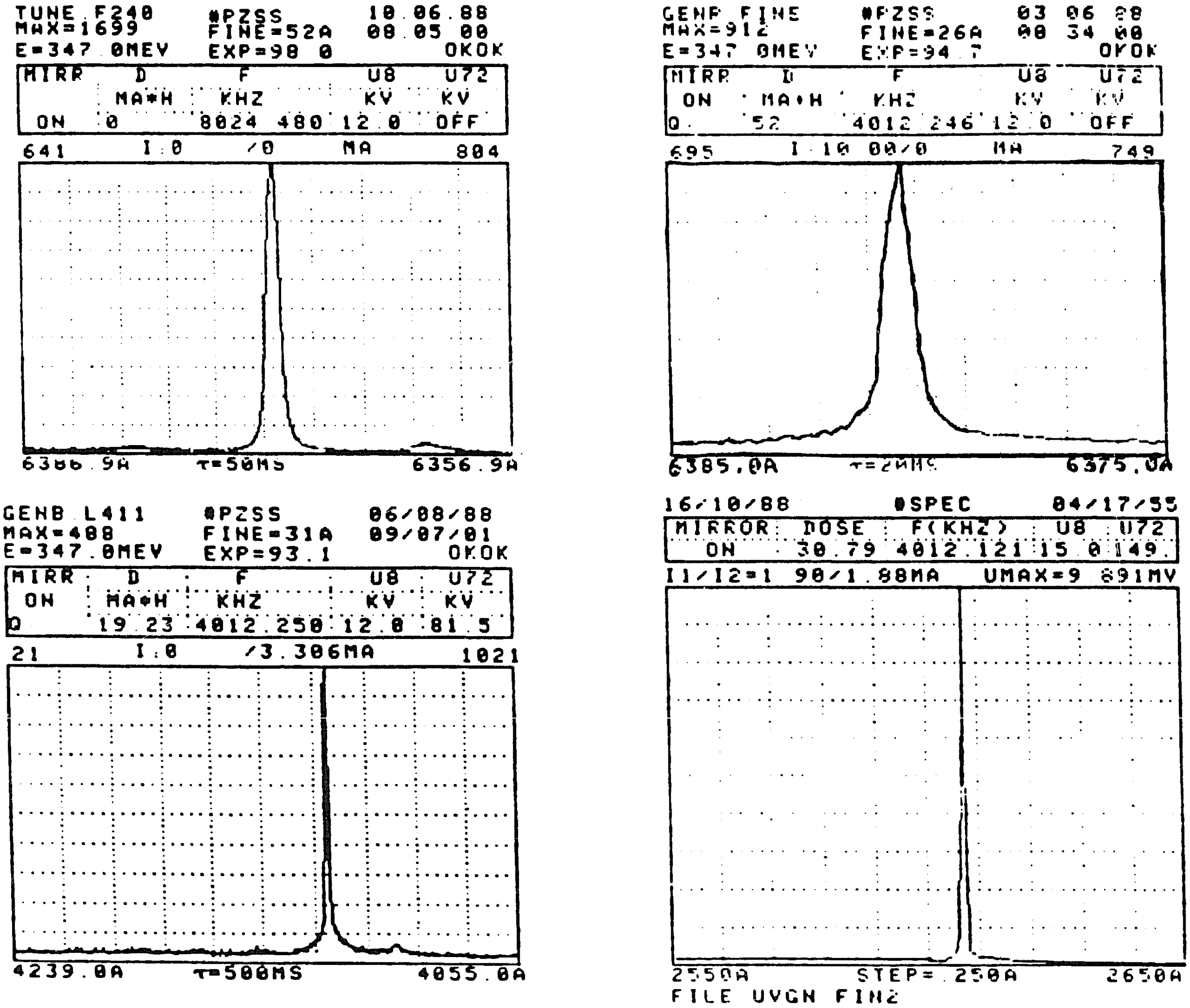

Fig. 3. Lasing lines in the red, violet and ultraviolet spectral regions, obtained on the OK-4.

The relative lasing line width $\Delta\lambda/\lambda$ varies within the $(1-5) \times 10^{-4}$ range, depending on the detuning of the electron-beam revolution frequency from the exact synchronism, on the beam current and on other parameters.

The transverse distribution of the radiation intensity corresponded to the basic mode (TEM_{00}) of the optical cavity.

Continuous tunability of the lasing wavelength was attained by changing the field in the undulators. Its boundaries (5800–6900 Å, 3750–4600 Å and 2400–2700 Å) corresponding to the reflection bands of the mirrors were used. The threshold current for lasing was 1–10 mA, depending on the optical-cavity mirror conditions.

The average lasing power is limited by electron-beam energy spread growth and is proportional to the full synchrotron radiation power and to the maximum admissible energy spread. In our case the maximum energy spread σ_E/E was limited by the gain reduction above the threshold and varies within the $(0.6-2) \times 10^{-3}$ range. The measured power (6 mW at 6300 Å and 2.5 mW at 2500 Å) at 20 mA average current corresponded to the expected values. Because only the average lasing power is limited, we realized a G-switching mode of OK operation to produce high peak power. The electron beam was shifted from the optical-cavity axis using electrostatic plates and was periodically returned to the initial position.

The typical pulse duration at 10 mA current was 0.1 ms and the power was about 50 W at 6300 Å and 18 W at 2500 Å wavelength. An increase in electron energy spread during lasing was observed in both cases (continuous and G-switch mode). The energy spread was calculated from the bunch length measured by a dissector [2] with 30 ps time resolution. The maximum measured relative energy spread (1.5×10^{-3}) was twice as large as the initial one.

5. Lased radiation time structure

For measurement of the radiation-time microstructure we used a dissector. The radiation bunch repetition frequency is $c/2L = 8$ MHz, where $L = 18.7$ m is the length of the optical cavity.

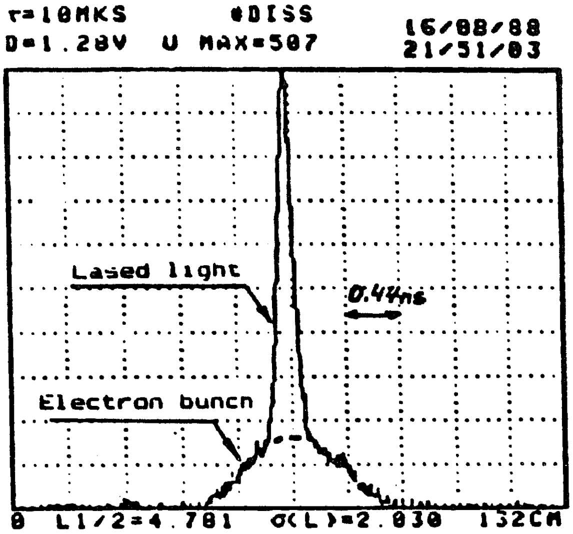

Fig. 4. The time microstructure of the electron and the lased bunches.

Fig. 4 shows the time structure of the electron beam (wide peak) and the lased beam (narrow peak on top of the electron beam). The pulse duration of the spontaneous radiation is equal to that of the electron bunch and the duration of the lased-beam pulse is considerably less. This is quite natural since the gain is proportional to the instantaneous value of the electron current and, consequently, is maximum in the centre of the bunch. The lasing micropulses have a duration of about 200 ps. According to this, the lased peak power is about 25 and 9 kW on 6300 and 2500 Å, respectively, in G-switch mode. Within the optical cavity the peak power was 2.5 and 1 MW, consequently.

6. Plans

Preparations for further increase of the lasing power and shortening of the lasing wavelength are in progress.

References

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[2] E.I. Zinin, Nucl. Instr. and Meth. 208 (1983) 439.
[3] V.N. Litvinenko, Synchr. Radiat. News 5 (1988) 18.