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DESIGN OF UVSOR LIGHT SOURCE AT IMS

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I. Summary

A 600 MeV electron storage ring dedicated to ultraviolet synchrotron orbital radiation research in molecular science and related fields has been designed. The maximum current is 500 mA with 1 hour Touschek lifetime. The photons in the 10-2000 Å region are mainly utilized. The ring is composed of eight bending magnet sections, and four long and four short straight sections. In both long and short straight sections, two doublets of quadrupoles are installed. From one bending section, two outlets of synchrotron radiation are available. To each outlet, two optical instruments will be attached. The emittance (ε_x) is typically $6\pi \times 10^{-8}$ m·rad, and the width ($2\sigma_x$) of the beam at bending section is 0.6 mm and the height ($2\sigma_z$) is 0.4 mm assuming 10 % x-z coupling. Undulators will be installed at two long straight sections, where dispersion function is 0 and beam divergence is small. The remaining one long straight section is reserved for an inflector. Another long straight section is reserved for an RF cavity (in future two cavities) and a wavelength shifter. Pulsed light (width ≈ 0.5 nsec, interval ≈ 180 nsec, in future, width ≈ 0.1 nsec, interval ≈ 360 nsec, 540 nsec ······) is available. The injector is a 600 MeV synchrotron with a 15 MeV linac. The synchrotron is composed of six bending magnet sections and six straight sections. In each straight section, a doublet of quadrupoles are installed. The current is 50 mA, and the repetition rate is 1 ~ 3 Hz.

II. Introduction

Since 1974, an electron storage ring dedicated to ultraviolet synchrotron orbital radiation research in molecular science and related fields has been proposed at the Institute for Molecular Science. This is a 600 MeV storage ring, the injector of which is a 600 MeV synchrotron with a 15 MeV linac.[1] The nickname is UVSOR. This project was initiated in 1980 with construction of optical instruments. Construction of light source itself is started in 1981 and will be completed in 1983. The photons in the 10-2000 Å region are mainly utilized ($\lambda_c = 56.9$ Å). In Fig. 1, the plane view of the UVSOR facility is shown. The synchrotron and the storage ring are under ground. The circumference of the ring is 53.2 m, which is twice as large as that of the synchrotron. The electrons are extracted from the synchrotron by the fast extraction method, transported under the floor of the storage ring room and injected from inner side of the ring, once to three times per second. Optical instruments are installed around the ring. During the injection period, experimentalists should be out of the synchrotron and the storage ring rooms. After the injection is over, they can have access to the ring and make measurements.

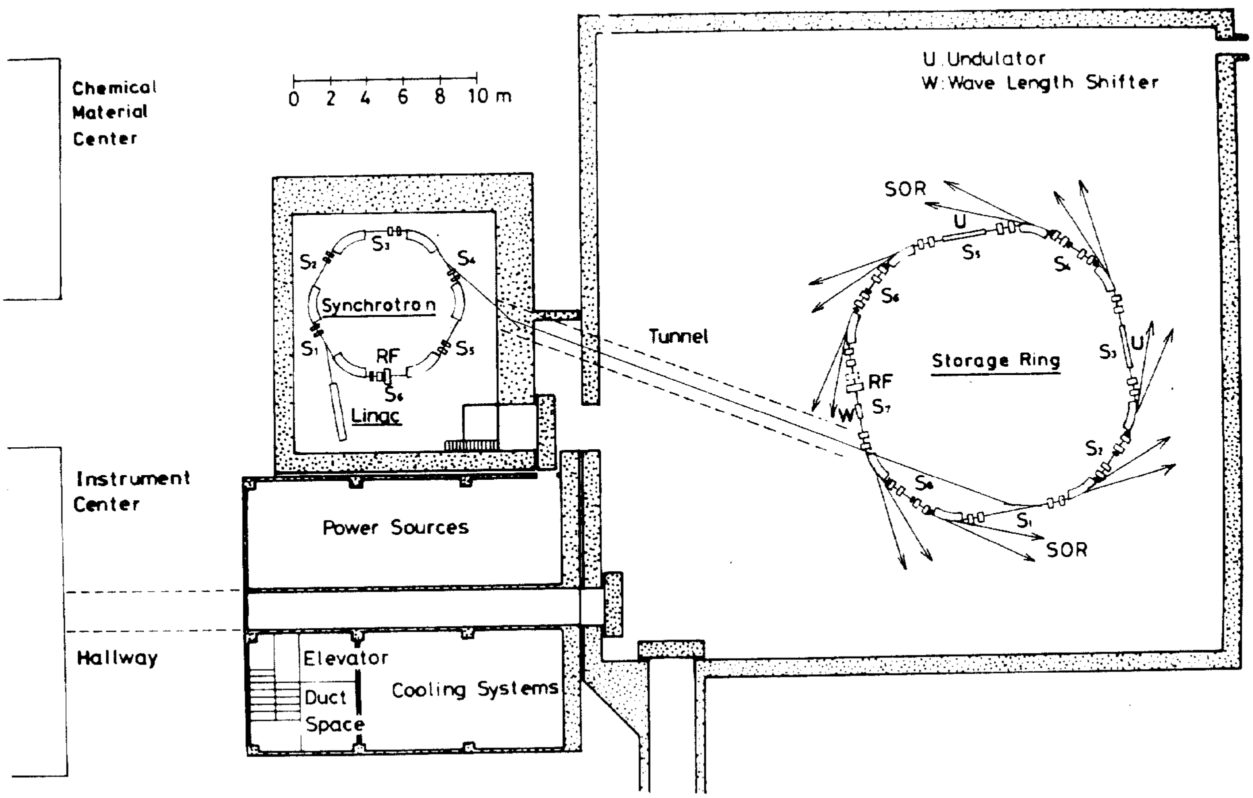

Fig. 1. Plane view of UVSOR facility (B2F)

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III. Synchrotron

The energy of the injector synchrotron is 600 MeV and its current is 50 mA. The maximum repetition rate is 3 Hz with the rise time of 0.15 sec. The synchrotron is composed of six bending magnet sections and six straight sections (see Fig. 1). The periodicity is 6. At each straight section, a doublet of quadrupoles are installed. An inflector for injection with pulsed electric field is located at S_1 straight section, three perturbators (bump magnets), at S_1, S_2 and S_6 sections, an RF cavity, at S_6 section, and a fast kicker and a deflector for extraction, at S_2 and S_4 sections. The radius of the bending magnet is 1.8 m. The circumference is 26.6 m. The betatron numbers are $\nu_x = 2.25$ and $\nu_z = 1.25$. Fig. 2 shows betatron (β_x, β_z) and energy dispersion (η) functions in a cell at the operation point ($\nu_x = 2.25$, $\nu_z = 1.25$), which are calculated using SYNCH program.[2] β_x is small at the bending magnet section and large at the straight section and β_z, *vise versa*. The maximum of η is about 1.4 m. Detailed parameters are given in Table I.

The injector of the synchrotron is a 15 MeV linac. The linac beam with the diameter smaller than 4 mm, the angular spread smaller than 2 mrad and the energy spread within 1 % (FWHM) can be captured by the synchrotron. For a single bunch operation of the synchrotron (the single bunch is used for the single bunch operation of the storage ring), short pulses (~ 5 nsec) or chopped ordinary-pulses (~ 1 μsec) will be used. An injection beam line is straight and the distance between a gun and the inflector is about 5.5 m. There are a doublet of quadrupoles for focusing, steering magnets and diagnostic components in the injection beam line.

The bending magnets have a C-shaped cross section. The gap is 5 cm and the width of the pole is about 20 cm. The n-value is 0. The central field is 11.1 kgauss. The bore radius is 4.7 cm and the maximum field gradient is 1 kgauss/cm. They are made of laminated silicon steel 0.35 mm thick. The bending magnets are excited by a thyristor-controlled power source and the quadrupoles are excited by two transistor-controlled power sources.

The maximum voltage of the RF cavity is 20 kV, which is sufficient enough to capture both coasting beams at the injection and accelerated beams emitting synchrotron radiation. The output power of a generator is 3 kW.

The vacuum chamber of the bending section is made of stainless steel bellows to prevent effects of eddy current. Conflat flanges are used. The average pressure in whole doughnut without baking is 1×10^{-6} Torr, which is low enough to garantee 0.1 sec lifetime of 15 MeV beam at the moment of injection. The extraction is made with a fast kicker with 60 nsec rise time and a deflector (septum magnet) excited sinusoidally with 1 kHz. The width of the beam at the moment of extraction becomes smaller than 2.5 mm due to the adiabatic and the radiation damping.

IV. Storage Ring

The energy of the storage ring is 600 MeV (20 ~ 30 % grade-up is possible) and the maximum current is 500 mA with 1 hour lifetime (Touschek lifetime). It is composed of eight bending magnet sections, and four long and four short straight sections (see Fig. 1). The periodicity is 4. At both long and short straight sections, two doublets of quadrupoles are installed. At each short straight section, three sextupoles are installed. An inflector for injection (septum magnet) is located at S_1 straight section, three perturbators (bump magnets), at S_1, S_2 and S_8 sections, an RF cavity (in future two cavities), at S_7 section. The S_3 and S_5 straight sections each have 3 m long free space, where undulators will be installed for the emission of quasi-

Table I. Design parameters of the synchrotron

Energy	600 MeV
Current	50 mA (~2.8×10^{10} electrons)
Circumference	26.6 m
Periodicity	6
Bending Magnet	
No.	6
Radius	1.8 m
Central Field	11.1 kgauss
n-value	0
Quadrupole Magnet	
No.	12
Length	0.25 m
Field Gradient	1 kgauss/cm
Betatron Number ν_x	2.25
ν_z	1.25
Natural Chromaticity ξ_x	-1.81
ξ_z	-1.77
RF Frequency	90.226 MHz
Harmonic Number	8
Momentum Compaction Factor	0.138
RF Voltage	20 kV
RF Power	3 kW
Pressure	1×10^{-6} Torr
Total Pumping Speed	2×10^3 l/sec
Repetition Rate	1 ~ 3 Hz
Radiation Damping Time τ_{β_x}	24.7 msec
τ_{β_z}	16.7 msec
τ_ε	7.2 msec
Injector	15 MeV Linac

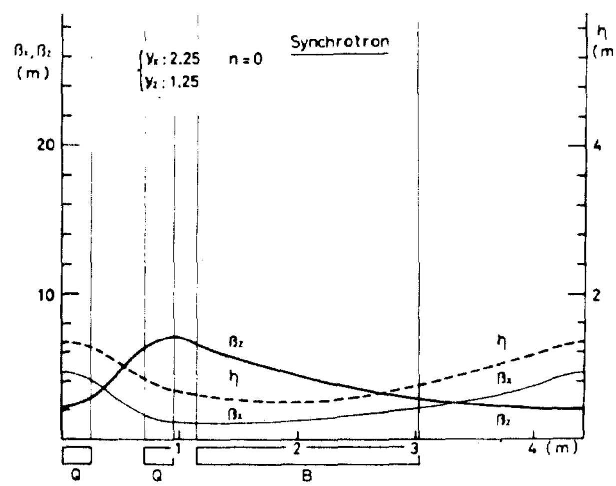

Fig. 2. Betatron and energy dispersion functions of the synchrotron (in a cell).

monochromatic light. A three poles wiggler with superconducting magnets will be installed in the remaining space of the S_7 section serving as a wavelength shifter for the measurements down to 5 Å.

The radius of the bending magnet is 2.2 m. The circumference is 53.2 m. The betatron numbers are $\nu_x = 3.25$ and $\nu_z = 2.75$. Fig. 3 shows betatron (β_x, β_z) and energy dispersion (η) functions in a half cell at the operating point ($\nu_x = 3.25$, $\nu_z = 2.75$), which are calculated using SYNCH program.[2] β_x is small at the bending magnet section and large at both long and short straight sections and β_z, *vise versa*. η is maximum at the center of the short straight section (≃ 1.8 m) and 0 at the long straight section. Emittance of x-direction is typically $6\pi \times 10^{-8}$ m.rad. Assuming 10 % x-z coupling, one can expect that the beam width at the bending section is 0.6 mm ($\sigma_x \simeq 0.3$ mm) and the height 0.4 mm ($\sigma_z \simeq 0.2$ mm). The injection rate is 1 ~ 3 Hz. Detailed parameters are given in Table II.

The bending magnets have a C-shaped cross section.

Table II. Design Parameters of the UVSOR Storage Ring

Energy	600 MeV
Critical Wavelength	56.9 Å
Current	500 mA (~5.5×10^{11} electrons)
Lifetime	1h (500 mA)
Circumference	53.2 m
Periodicity	4
Bending Magnet	
No.	8
Radius	2.2 m
Central Field	9.09 kgauss
n-value	0.5
Quadrupole Magnet	
No.	32
Length	0.2 m
Field Gradient	1 kgauss/cm
Sextupole Magnet	
No.	12
Length	0.1 m
Betatron Number ν_x	3.25
ν_z	2.75
Natural Chromaticity ξ_x	-4.5
ξ_z	-4.2
RF Frequency	90.226 MHz
Harmonic Number	16
Momentum Compaction Factor	0.028
Radiation Loss/turn/el.	5.21 keV
Radiation Loss/sec	2.6 kW (500 mA)
RF Voltage	50 kV
RF Power (Amplifier)	20 kW
Pressure (500 mA)	1×10^{-9} Torr
Total Pumping Speed	2×10^{4} l/sec
Radiation Damping Time $\tau_{\beta x}$	40.9 msec
$\tau_{\beta z}$	40.9 msec
τ_{ε}	20.4 msec
Emittance ε_x	$6\pi\times10^{-8}$ m·rad
ε_z	$6\pi\times10^{-9}$ m·rad*
Beam Size at Bending Section	
σ_x	0.3 mm
σ_z	0.2 mm
Injection Rate	1 ~ 3 Hz

* 10 % coupling is assumed.

The gap is about 5 cm and the width of the pole is about 20 cm. The field index is 0.5. The central field is 9.09 kgauss. The bore radius of the quadrapoles is about 5 cm and the maximum field gradient is 1 kgauss/cm.

At 600 MeV the radiation loss per turn per electron is 5.21 keV and the total energy loss for stored current of 500 mA is 2.6 kW. The peak voltage of the RF cavity is 50 kV and the output power of a generator is 20 kW. The RF frequency of the storage ring is usually equal to that of the synchrotron and is 90.226 MHz. The harmonic number is 16. Single bunch operation is possible so as to attain the pulsed light with 0.5 nsec width and about 180 nsec interval. To shorten the pulse width at the single bunch operation, the RF cavity of higher frequency will be installed like BESSY[3] (for instance 360.904 MHz). It is possible to inject a single bunch into one bucket of the RF of the storage ring having such higher frequency, because the bunch length in the synchrotron is about 1/10 of the wavelength of the synchrotron's RF.

To elongate the pulse interval in the single bunch operation, two pairs of the electrodes separating by phase advance of π will be installed up-stream and down-stream of a benidng magnet. These electrodes deflect a single bunch in z-direction with the revolution frequency divided by integers above 4. This device will make the elongation of the pulse interval by 360 nsec, 540 nsec, ······ possible.

The vacuum doughnut is made of stainless steel with conflat flanges. The pressure in the doughnut must be lower than 1×10^{-9} Torr in order to attain the lifetime

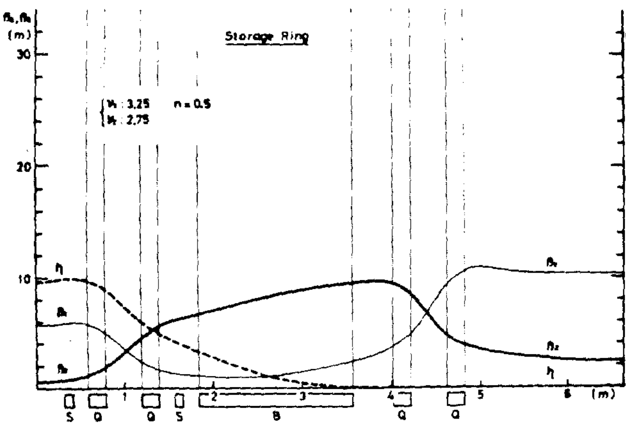

Fig. 3. Betatron and energy dispertion functions of the storage ring (in a half cell).

of about 1 day governed by collisions with residual gases. The straight sections are evacuated by sputter ion pumps and titanium sublimation pumps, and the bending sections are evacuated by the so-called built-in pumps, which utilize fringing field of the bending magnets and pump out the desorbed gas from the walls irradiated by the synchrotron radiation. The total amount of pumping speed is 2×10^{4} l/sec. The baking of the bending sections will be made by resistively flowing 1 kA through them. Argon discharge cleaning will also be used.

From one bending section, two outlets for the synchrotron radiation are available. To each outlet, two optical instruments are attached. The synchrotron radiation is divided using a pre-mirror. Each optical instrument can utilize the synchrotron radiation with a horizontal angle spread of 10 mrad. The outlet is made of a pipe 30 cm in diameter and 2 m long, in which several diaphragms are installed and to which a fast closing value is attached. This pipe serves both as a differential pumping system between the ring and the optical instruments and a delay line which delays the propagation time of the shock wave caused by the accidental leakage of air,[4,5] by the time durations sufficiently longer than the closing time of the fast closing valve.

Acknowledgments

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