PHYSICAL DESIGN OF AN 800 MEV ELECTRON STORAGE RING
DEDICATED TO SYNCHROTRON RADIATION

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1. Introduction

The design study of an 800 MeV electron storage ring of National Synchrotron Radiation Laboratory in Hefei has been completed. It is just now being built. This storage ring is a facility dedicated to synchrotron radiation research.[1]

Its design considerations are to satisfy the demands of synchrotron radiation users as far as possible. This facility can provide a broad spectrum from the vacuum ultraviolet to the soft X-ray region. It will be available for the physics, chemistry, biology, metrology, and X-ray lithography.

A proposal to build the synchrotron radiation facility was first put forward in the late 1977. The design study of the storage ring began in the spring of 1978, and it was completed in the autumn of 1981. This project was authorized by the government in April 1983. It is hoped that this machine will have been built by 1987.

2. The Parameters Choice of The Storage Ring

The choice of the storage ring energy of 800 MeV is based on numerous discussions with the scientists of related subjects at home and abroad. The available wavelength range of the radiation provided by electron storage ring of this energy can meet the requirements of most users in China, for example, the wavelength range about 10-50 Å, which is demanded by the users working in the field of soft X-ray lighography and microfabrication, is just around its characteristic wavelength λ_c =24 Å.

The characteristic wavelength of synchrotron radiation is determined by the electron energy and the curvature radius of electron orbit. We chose the field strength of the bending magnet as 1.2 Tesla, and the curvature radius of the electron orbit is 2.2221 meters. The stored beam current will be expected up to about 300 mA.

In order to meet the requirements of the users working in the field of hard X-ray research, a superconducting wiggler of 5 Tesla is planned to install in the storage ring, and its λ_c =5.8 Å, then the available wavelength range is extended to about 1.2 Å.

The spectral distribution of photon fluxes of the storage ring is given in Fig. 1.

3. The Lattice of The Storage Ring

The lattice structure of the storage ring is a strong focussing type of seperated function, which consists of 12 bending magnets and 32 guadrupoles. It has four superperiods, with four fold symmetries. The circumference of the ring is 66.1308 meters. The length of each bending magnet is 1.1635 meters. Each quadrupole has a length of 0.3 meter. It is necessary to have four long straight sections of 3.36 m for injection, RF cavity, wiggler and undulator or free electron laser respectively. In order to install kickers, pumps, flanges, vacuum meters, and detectors of beam measurement etc, there are 24 medium straight sections of 1.0 m in the ring.[2] The plane layout of the storage ring is shown in Fig. 2. The lattice and elements sizes of a superperiod are illustrated in Fig. 3.

The properties of synchrotron light depend on the size of electron beam in bending magnet, and the size of beam in bending magnet is

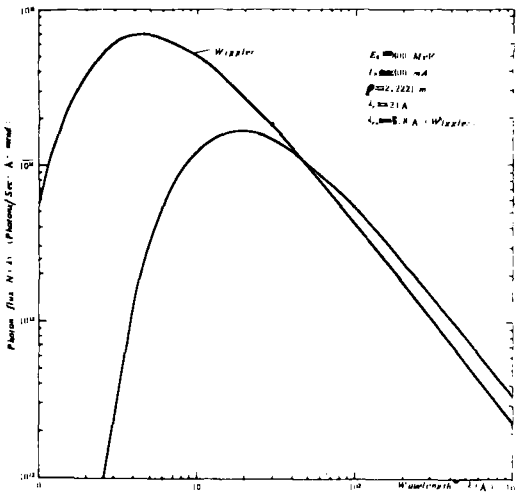

Fig.1. Synchrotron Radiation Photon Flux

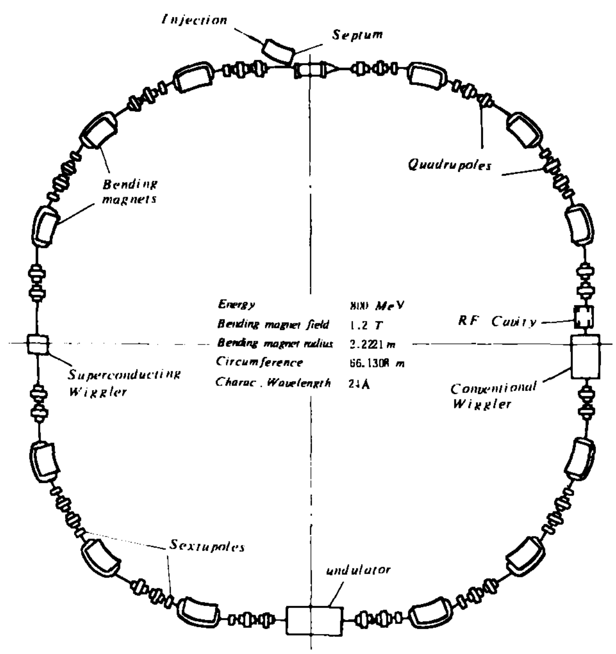

Fig.2. Plane Layout of The Storage Ring.

determined by the lattice of the storage ring. In order to meet the different requirements of the synchrotron radiation users, we designed

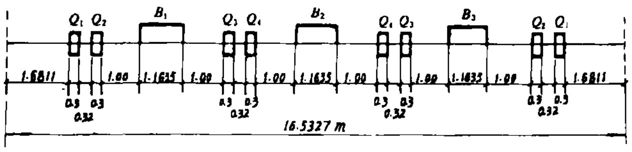

Fig. 3. Lattice Structure of The Storage Ring (one quadrant)

the lattice of the storage ring with four different operating configurations, in other words, it's four light sources with different characteristics. The four light sources are:

(1) General Purpose Light Source (GPLS): It has long beam lifetime, moderate brightness. The difference resonance is adopted between the horizontal and vertical oscillations to enlarge the beam cross section for increasing beam lifetime. This light source is suitable to the most users of physics, chemistry, biology, etc.

(2) High Flux Light Source (HFLS): The beam size of this light source is large. It has high photon flux, long beam lifetime, but low brightness. This light source is suited to lithography technique. Becauce lithography are asking for a high photon flux, and the cross section of beam are not important.[3]

(3) High Brightness Light Source (HBLS): In this operating configuration the cross section of beam is extremely small, therefore the brightness of light source is very high. It can be used for the experiments of high space resolution and metrology standard.

(4) Short Pulse Light Source (SPLS): This source has very short beam length (~ 4mm), and therefore the pulse of light is extremely short (~10^{-11} sec), it can be used for the experiments of high time resolution.

In above operating configurations, except SPLS, the long straight section where wiggler and RF cavity located is achromatic (η =0). The lattice parameters and beam parameters of the four configurations are listed in table 1.

The β and η functions were calculated according to the single particle dynamics theory.[4] As an example, the curves of β, η functions and beam size of the HBLS are shown in Fig. 4. The brightness of synchrotron radiation light is calculated using formula of the short light source approximation.[5]

4. Injector

The injector is an electron linac with operating energy of 200 MeV. It consists of 9 accelerating sections, a buncher, and a prebuncher. The total length is 35.5 m. The accelerating cavity are of 2/3 mode, disk-loaded wave guide, constant impedance homogeneous structure. Its operating freguency is 2856 MHz. The

Table 1. The Lattice Parameters and Beam Parameters

		GPLS	HFLS	HBLS	SPLS
focussing strength of quadrupoles (m^{-2})	K_1	-1.95	1.26	-2.88	-2.94
	K_2	2.74	-1.02	4.17	2.85
	K_3	-2.61	-1.27	4.66	-3.80
	K_4	3.17	2.75	-2.47	4.02
betatron oscillation frequency	ν_x	3.76	2.76	5.84	3.18
	ν_z	2.76	1.76	2.76	4.22
maximum β and η functions (m)	β_{xmax}	8.93	15.19	18.06	13.54
	β_{zmax}	8.41	18.06	17.57	18.83
	η_{max}	1.66	1.43	0.87	1.62
momentum compaction	α	0.05	0.0422	0.0112	0.00012
natural chromaticities	ξ_x	-4.15	-3.00	-20.72	-6.17
	ξ_z	-4.71	-5.80	-9.01	-16.22
coupling coefficient	k	1.0	1.0	0.1	0.1
beam size (mm)	$\sigma_{x1}(B_1)$	0.54	1.05	0.056	2.07
	$\sigma_{z1}(B_1)$	0.76	1.76	0.046	0.31
	$\sigma_{x2}(B_2)$	0.80	0.64	0.10	0.87
	$\sigma_{z2}(B_2)$	0.46	0.06	0.15	0.63
	$\sigma_{xw}(W)$	0.58	1.69	0.30	1.75
	$\sigma_{zw}(W)$	0.58	1.43	0.11	1.07
	σ_s	34.0	33.6	17.3	1.8
emittance (mm.mrad)	ε_x	0.095	0.19	0.0123	0.61
	ε_z	0.095	0.19	0.00123	0.061
brightness (Photons/sec. A.mm^2. $mrad^2$. 1% bandwidth	$B_{r1}(B_1)$	4.8×10^{13}	1.1×10^{13}	7.6×10^{15}	3.1×10^{13}
	$B_{r2}(B_2)$	5.3×10^{13}	5.2×10^{13}	1.3×10^{15}	3.6×10^{13}
	$B_{rw}(W)$	5.8×10^{13}	0.8×10^{13}	0.6×10^{15}	1.1×10^{13}

pulse current is 50 mA. It can provide a few pulses per second to 50 pulses per second, the pulse duration are 2ns, 4ns, 0.2–1 μs

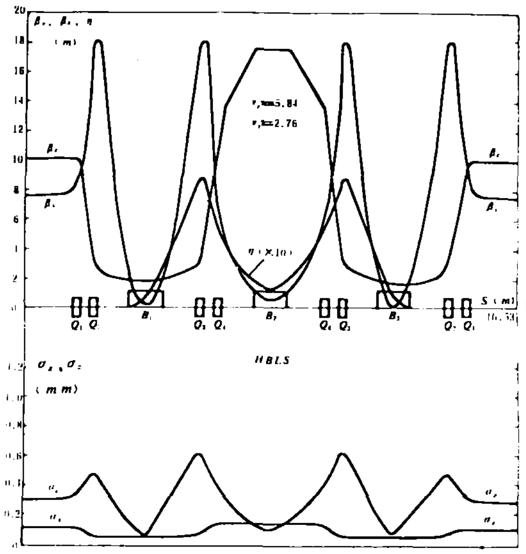

Fig. 4. β, η functions and beam size

5. The RF System

The RF system has been designed. The RF accelerating cavity has a resonant frequency of 204 MHz. The reason for choosing this resonant freguency is that there is the 204 MHz RF power generator in our country at present. The RF harmonic number is 45, and the frequencies of linac and storage ring are related (integer multiple of 14).

The peak accelerating voltage of 100 KV with an over voltage factor of about 6 ensures enough large bucket and quantum lifetime.

The power output of the RF generator is 20 KW. The radiation power of the stored electrons is 4.89 KW corresponding to a beam current of 300 mA.

The injection time of the electron beam is about a few minutes and the ramping from 200 MeV to 800 MeV requires about 3 minutes, then the beam will be stored. In the injection stage the RF voltage is about 40 KV, and in the ramping acceleration stage and storage stage the RF voltage increases from 40 KV to 100 KV.

6. The Vacuum Chamber

The vacuum chamber aperture is determined by the transverse size of the beam. According to the calculation of the quantum lifetime of the stored beam, the vacuum chamber aperture must be larger than $12\sigma_x$ [6] (σ_x is half width of the beam). In order to obtain the quantum lifetime longer than 100 hr, the vacuum chamber aperture is adopted as $20\sigma_x + X_c$ and $20\sigma_z + Z_c$ (X_c, Z_c are closed orbit distortions). The cross section of the vacuum chamber is 80X40 mm^2. The chamber will be made of stainless steel, the chamber wall is 4 mm. In consideration of the installation tolerance, we take the gap of bending magnet as 55 mm. The vacuum chamber of the storage ring have been designed with an operating pressure of about 10^{-9} Torr.

7. Beam Lifetime

The beam lifetime depends on various factors such as quantum effect, gas scattering and Touschek effect. The calculations have shown that the quantum lifetime is much longer than 100 hours; While the gas pressure is less than 10^{-9} torr, the gas scattering lifetime is more than 24 hours. Therefore, the beam lifetime mainly depends on the Touschek effect in our case.[7] The Touschek lifetimes of the four operating configurations are shown in the table 2. (E_0 = 800 MeV)

Table 2. The Touschek Lifetime of The Stored Beam (τ_T)

	GPLS	HFLS	HBLS	SPLS
$I \cdot \tau_T$(A.h)	4.1	20.7	0.15	$1.1\text{X}10^3$

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