Compact Electron Storage Ring JESCOS with Normalconducting or Superconducting Magnets for X-ray Lithography

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Abstract

The layouts of a normal conducting electron storage ring and a storage ring with superconducting bending magnets are presented. The storage rings have a critical wavelength of 1 nm and are designed as compact sources for X-ray lithography. Each ring fits into a shielded room with a diameter of 14 m.

INTRODUCTION

X-ray lithography is under development to become an industrial tool in the large scale production of highly integrated computer memory chips. While for 64 MBit chips, the resolution needed can probably be reached by advanced light optics methods, it seems likely nowadays, that for the 256 MBit chip generation, X-rays will be used for the imaging of the mask to the substrate. The radiation has to be highly parallel. Thus, the appropriate X-ray source is an electron storage ring in the 1 GeV energy regime, emitting the forward boosted synchrotron radiation from the orbit of the electrons.

The first compact storage ring proposed in 1982 was "Klein-Erna" [1], a "table-top" synchrotron radiation source. Among the compact sources realized, COSY at BESSY/FhG in Berlin was used as an experimental machine [2], while IBM's HELIOS is used in a pilot chip production facility at East Fishkill, New York [3]. Both concepts are based on a pair of superconducting 180^0 magnets.

For industrial applications, the floorspace needed by the storage ring has to be kept small, related to the scale of a production line with the beamlines and the clean rooms. Compactness, however, is not the only criterion for the storage ring. The most important objective in large scale chip production is a permanent and reliable operation of the radiation source.

We have designed two compact electron storage rings JESCOS and JESCOS-N as sources for synchrotron radiation, each of them covering the range of critical wavelengths between 0.8 nm and 1.2 nm. The JESCOS ring with an electron energy of 700 MeV has two superconducting 180^0 bending magnets at a magnetic field of 4.5 T, which are entirely new designed, based on the experience from the Berlin COSY magnets. The JESCOS-N ring with an energy of 1.2 GeV uses eight normalconducting bending magnets with maximum fields of 1.6 T. Each of the two rings fits comfortably into a room with a diameter of 14 m, which is a reasonable size for the radiation shielded area in a chip production environment.

THE SUPERCONDUCTING STORAGE RING

The compact synchrotron radiation source JESCOS is based on the racetrack geometry using two superconducting 180^0 bending magnets (figure 1). The main parameters are listed in table 1. The ring is laid out for an energy of the stored electrons of 630 MeV to 720 MeV, corresponding to an adjustable critical wavelength between 1.2 nm and 0.8 nm. The 500 MHz RF system is designed for a stored beam current of 230 mA at 720 MeV and 400 mA at 630 MeV, thus resulting in a total radiated power of 7.5 kW independently of the selected electron energy.

In order to reach a rather low horizontal emittance of 7×10^{-7} m rad, it is necessary to keep the beta functions and the dispersion function in the dipole magnets low. This is accomplished by eight normalconducting quadrupole magnets in two electrical families, which are placed in the straight sections. The dipole magnets have a field index of n = 0.525. The lattice functions are shown in Figure 2. Four separate sextupole magnets are foreseen for chromaticity correction. Tracking calculations with RACETRACK, including the effects of sextupole components in the coil heads of the dipoles, yield a dynamic aperture of more than 16 standard deviations, which is comfortable.

Table 1. Main Parameters of the Compact Synchrotron Radiation Sources

	JESCOS	JESCOS-N
max. energy	722 MeV	1.2 GeV
crit. wavelength	0.8...1.2 nm	
max. current	400 mA	240 mA
radiated power	> 7.5 kW	
beam lifetime	5 h	6 h
circumference	12 m	28.75 m
bending magnets	2 x 180^0	8 x 45^0
bending field	4.5 T	1.6 T
bending radius	0.53 m	2.5 m
injection energy	100 MeV	

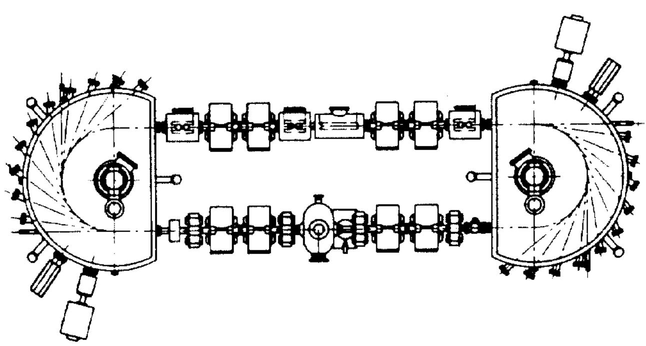

Figure 1. Compact Electron Storage Ring JESCOS, total length 6.5 m

The injection energy into the storage ring is planned to be 100 MeV, using a microtron with a current of 15 mA as injector, which is placed below the storage ring. The low emittance of the microtron of 10^{-7} m rad and its relatively long pulse time of 0.1 μs to 1 μs allow a multi turn injection into 3 up to 7 turns. Three fast kicker magnets with a pulse time of 130 ns produce a closed orbit bump during injection. Accumulation of the design currents is estimated to take about 30 s. Ramping down the superconducting magnets from the storage energy to the injection energy takes 60 s, while ramping up again will be done in 240 s. The estimated life time of the stored beam is 5 hours. In the routine service of the radiation source, an injection cycle will be executed every 1.5 hours. Thus, the the time needed for ramping and injection consumes less than 5 % of the total beam time.

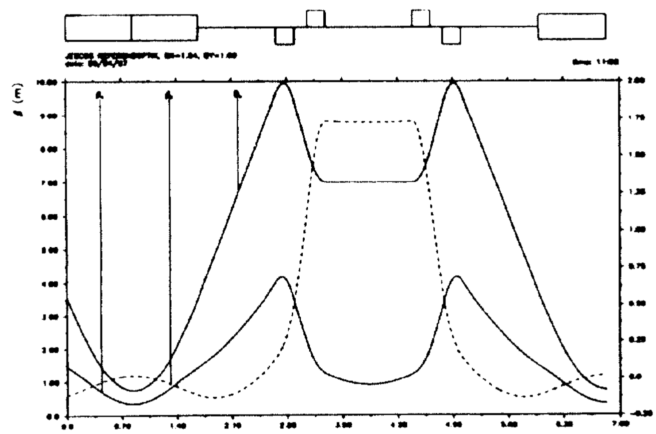

Figure 2. Lattice Functions of the Superconducting Storage Ring

The design of the machine was oriented towards highest reliability. The revised design of the superconducting magnets is based on the experience from the Berlin COSY magnets and has improved magnetic field properties and cryomechanical behaviour of the coils.

THE NORMALCONDUCTING STORAGE RING

The compact synchrotron radiation source JESCOS-N with a maximum electron energy of 1.2 GeV is based on eight normalconducting bending magnets (figure 3). The main parameters of JESCOS-N are given in table 1. The properties of the emitted radiation spectrum of the normalconducting JESCOS-N are comparable to those of the superconducting JESCOS. A magnetic field induction of no more than 1.6 T in the dipole magnets was chosen, in order to secure highest reliability. The 500 MHz RF system is laid out for a stored current of 140 mA at 1.2 GeV and of 240 mA at 1.05 GeV, corresponding to critical wavelengths of 0.8 nm and 1.2 nm, respectively. The total radiated power is 7.5 kW for all electron energies selected.

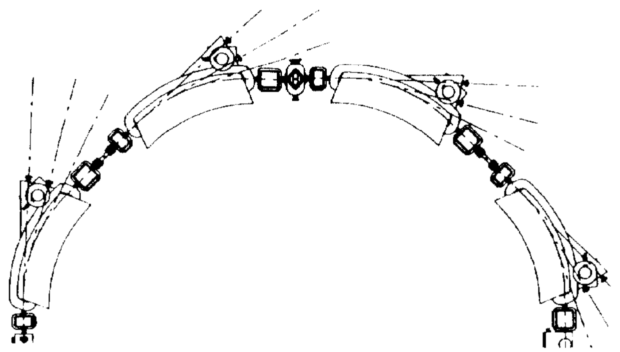

Figure 3. Half of Compact Electron Storage Ring JESCOS-N, diameter 8.9 m

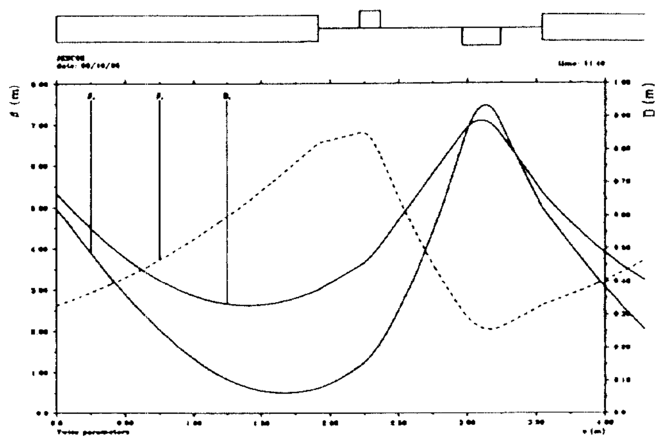

Figure 4. Lattice Functions of the Normalconducting Storage Ring

The lattice (figure 4) has an eightfold symmetry with rectangular dipole magnets and two families of quadrupoles. The equilibrium emittance is 1×10^{-7} m rad. Chromaticity correction is accomplished by eight sextupoles in two families. The dynamic aperture of the corrected machine is about 30 standard deviations.

For injection, again, a 100 MeV racetrack microtron is proposed, which is put below the storage ring for the sake of compactness.

COMPARISON OF THE DESIGNS

Figure 5 indicates clearly, that both the superconducting source JESCOS and the normalconducting source JESCOS-N fit equally well into a typical lithography facility environment. The radiation shielding wall in this case has an inner diameter of 14 m, and 12 resp. 14 stepper stations with 10 m long x-ray beamlines can be arranged around the source.

The total electrical power consumption of the superconducting JESCOS amounts to 430 kW including the refrigerator, while the normalconducting JESCOS-N has a power consumption of 510 kW.

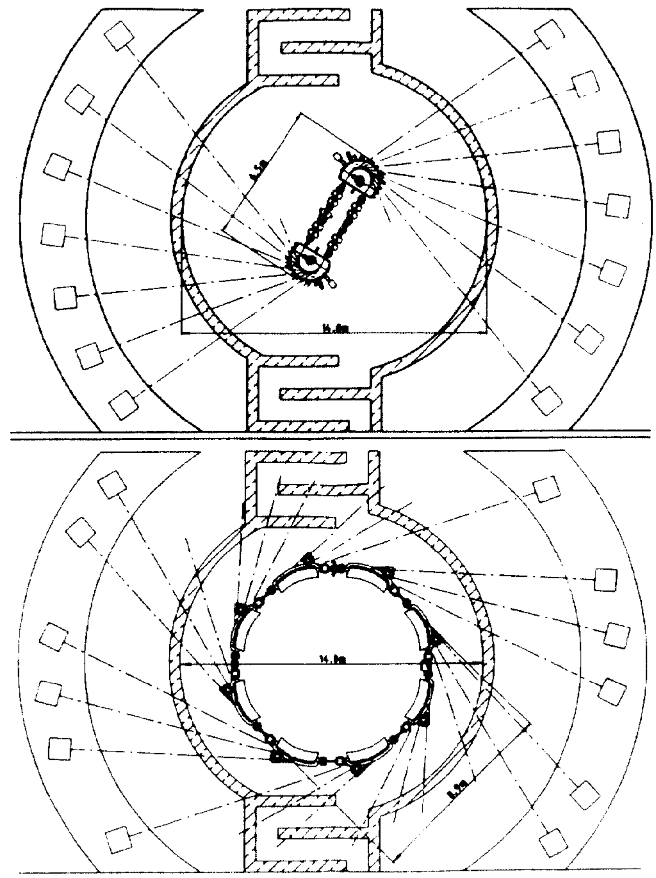

Fig. 5. JESCOS and JESCOS-N in a typical lithography facility

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