MARS - A PROJECT OF THE DIFFRACTION LIMITED FOURTH GENERATION X-RAY SOURCE

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Abstract

The paper describes a proposal of the 4th generation light sourse MARS. Main goal of the MARS (Multiturn Accelerator-Recuperator Source) is providing the diffraction limited undulator radiation (UR) in the 0.01-4 nm wavelength range with average brightness of about 10^{23} phot/s/mm^2/mr^2/0.1%BW.

1 INTRODUCTION

Various kinds of proposal for 4th generation light source are being discussed intensively for the last several years [1,2]. Two main approaches are: (i) advanced storage ring equipped with a long undulator (hundred meter), (ii) X-ray FEL with linac as the electron source. For both approaches the electron energy more than 5 GeV and emittance less than 10^{-11} m-rad are necessary. For the first case the average current should be rather high (tens milliampers) but peak current is low (<1 A). On the contrary, the second approach uses rather high peak current (several kiloampers) but low average one (<10^{-7} A). Today both approaches suffer from yet unsolved technical and physical problems. In storage rings, where beam emittance and energy spread are determined mainly by quantum fluctuation of SR and intrabeam scattering, lattices for the emittance minimization seem to reach their limit ($\varepsilon_x > 10^{-10}$ m-rad, $\sigma_E/E \sim 10^{-3}$). One of the main problems of the linac FEL is the emittance growth due to the strong space charge induced forces.

In [3] a new approach based on the multiturn accelerator-recuperator was proposed. Main motivation for our project was to combine the advantages of both above approaches. The following requirements for 4th generation light sources were taken into account for this proposal:

- average brightness of UR in the 0.01-4 nm wavelength range >10^{22}-10^{23} ph/s/mm^2/mr^2/0.1% BW;
- brightness should increase without full photon flux increasing, in other words, total average power of undulator radiation should be ~ 1 kW.

A high quality electron beam of ~1 mA current travels through long undulator that produce an extremely bright UR. As accelerator we propose to use recirculating RF recuperator[4]. RF system, that is a key system of accelerator, can be designed using technological approaches which are well-developed for such machines like LEP, PEP, TRISTAN, etc. The energy recovery is necessary to reduce both the RF system power and radiation hazard. Same kind but low energy (100 MeV) machine is under construction in Novosibirsk now[5].

2 ACCELERATOR

MARS is based on the recirculating RF accelerator-recuperator. A good quality (low emittance and energy spread) beam from electron gun is accelerated by the linac-preinjector, composed of the same RF cavities as the main accelerating structure, up to 200 MeV and injected into the racetrack accelerator-recuperator (Fig.1). Then the electron beam passes through the main accelerating RF structure 17 times and is accelerated to 5.3 GeV. At the last turns the beam travels through the long undulators installed in the straight section where the lattice functions are arranged in such a way to provide optimum conditions for radiation. The «exhausted» beam is decelerating in the recuperator, returning energy to RF generators and absorbing in the beam dump. Energy recovery is required to reduce both power of the RF system and radiation hazard. Quadrupole magnets arrangement in the accelerating sections provides focusing for the beams of all energy set (from 200 MeV to 5.3 GeV). Arcs consist of lattice cells optimized to minimize the single-turn emittance and energy spread growth due to the quantum radiation effects.

Main parameters of the MARS accelerator-recuperator are given in Table 1 and magnet parameters are listed in Table 2.

Table 1: Electron beam parameters.

Energy	GeV	5.3
Average current	mA	1.0
Peak current	mA	1000
Emittance	m-rad	2×10^{-12}
Relative energy spread		2.4×10^{-5}
Circumfer. of last turn	m	944
Energy loss in last arcs	MeV	1.37

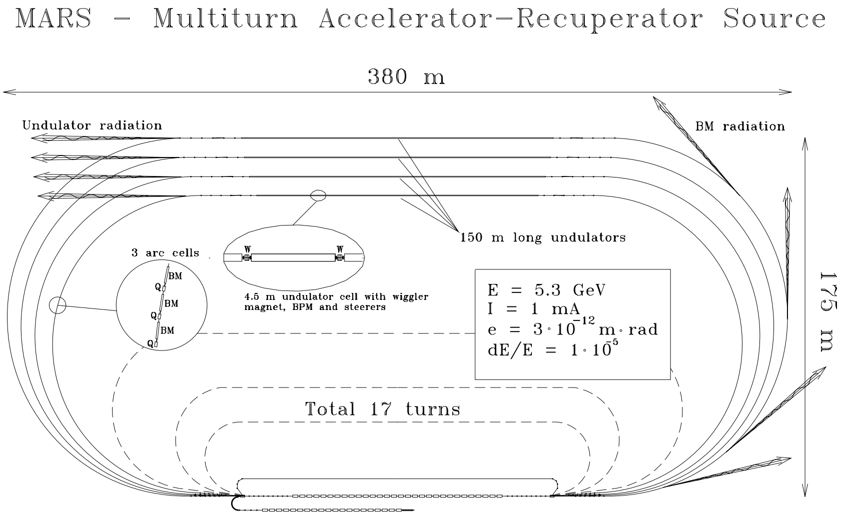

Fig.1: Layout of the MARS light source

To reduce the RF system power consumption and number of cavities, superconducting LEP type cavities could be used for the project. Each RF cell consists of 4 superconducting cavities in a single cryostat. Total length of one RF cell is about 2.5 m. LEP type RF cavity parameters are given in Table 3.

Table 2: Magnetic system parameters (@5.3 GeV).

Dipole magnet		Dipole	Quad
- No.of magnets		1400	1700
max. Field (or gradient)	T (T/m)	0.347	26
- bending radius	m	50.9	
- magnetic length	m	2.0	0.6
- bending angle		2.25°	
- crit.photon energy	keV	6.48	

Table 3: Superconducting RF cavity parameters.

RF frequency	MHz	352
No.cells/cryostat		4
Cell diameter	m	0.753
Total length	m	2.4
Accelerating field	MV/m	≥5
Quality factor		$\geq 2\times10^{9}$
Loaded quality factor		4×10^{6}

The calculated horizontal emittance as a function of energy is in Fig.3. Adiabatic damping and radiation effects were taken into consideration.

3 LONG UNDULATOR

A planar undulator of 150 m long (about 10000 periods with λ_0 = 1.5 cm) is split to the cells, each of 4.5 m in length (300 periods), with 0.5 m straight section in between. Each straight section contains 3-pole phase shifter to adjust the phase error, steering magnets and beam position monitor.

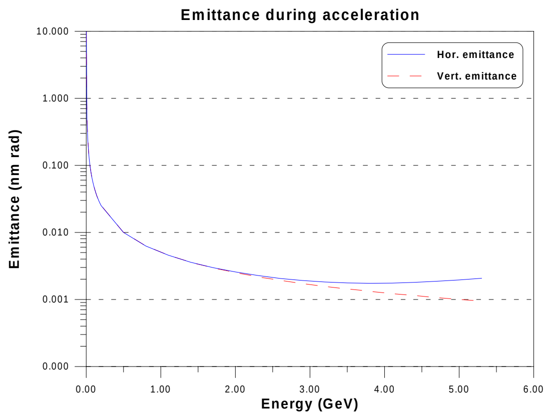

Fig.3: The dependence of the beam emittance on accelerating energy.

Short period of the undulator and its big length cause strong requirements for the undulator field errors and the electron beam trajectory displacement inside. Estimation shows that the transverse displacement and angular divergence of the beam along the undulator must be not more than $\Delta X \cong 10$ μm and $\Delta X' \cong 1$ μrad respectively. This yields the requirement to the integral value of the field error at the undulator length as 1.5×10^{-5} Tm that gives for $K = 1$ and $H_0 \cong 0.65$ T the relative field error for one pole about 0.5%.

Table 4: Main parameters of the MARS long undulator

No.of periods (34 cells)		10200
Period	mm	15
Gap	mm	≅5
Field amplitude	T	≅0.65
Undulator parameter		1
Fundament. Wavelength	Å	1.0
Fundamental energy	keV	12.4

As a proposal for the MARS project we chose an equipotential-bus electromagnetic undulator that combines in its design electromagnets and permanent magnets [6]. Four current buses excite the magnetic field and allow individual adjustment of each undulator cell. The undulator of such a design is not too sensitive to the temperature change and requires less tolerance for permanent magnets. The parameters of the undulator are given in Table 4.

The final adjustment of steering coils, phase shifters and field amplitudes in the undulator sections may be done by the measurements of the radiation spectrum.

4 MARS RADIATION PROPERTIES

Main radiation sources of the MARS accelerator-recuperator are:

- Long undulator(s) which can be installed in the straight section of the last turn(s). Here we consider only one 150 m long undulator in the straight section of the last turn (5.3 GeV),
- Bending magnets in the arcs where lattice functions are optimized to have low emittance, and the beam size in the center of the magnet is rather small.

The parameters of the accelerator for which radiation properties have been evaluated are given in Table 1.

A summary for the MARS radiation parameters are given in Table 5. A fundamental wavelength is presented for the undulator and the critical one for the bending magnet.

Table 5: Radiation parameters.

		Undulator	Bend. magnet
Field	T	0.65	0.35
Period	mm	15	-
λ_c or λ_1	A	1.0	1.9
Brig(λ_c or λ_1)	Ph/s/mr^2/mm^2/ 0.1%BW	1.4×10^{23}	1×10^{17}

Fig. 4 depicts the radiation brightness for the MARS long undulator.

5 CONCLUSIONS

In this paper we propose a new approach to the design of the 4th generation of synchrotron light source. The design is based not on the traditional storage ring or linear accelerator but on the recirculating accelerator-recuperator as the electron beam source and long undulator as the main radiation source. The advantages of this approach are as follows:

- As the time of the acceleration is rather small compare to the characteristic times of the main diffusion processes, the last can not «spoil» such important beam parameters as emittances and energy spread;

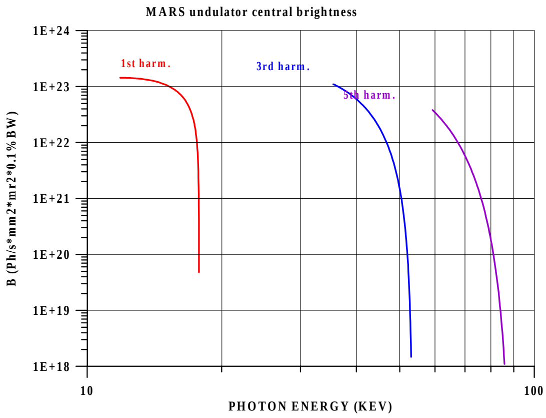

Fig.4: MARS undulator radiation brightness.

- In this case the emittance and the relative energy spread due to the adiabatic damping can reach the values of 3×10^{-12} m-rad and 2.4×10^{-5};
- The average radiation brightness from the undulator is about 10^{23} phot/s/mm^2/mr^2/0.1%BW for 10-60 keV radiation energy region (1st, 3rd, and 5th harmonics);
- It is important that this brightness increase does not lead to the drastic growth of radiation power: undulator radiation power is about 2 kW and the problem of the power load of the experimental equipment is not so serious;
- Bending magnets radiation brightness is 10^{17} phot/s/mm^2/mr^2/0.1%BW at 10 keV;
- Accelerator-recuperator avoids many non-linear problems which are typical for the storage rings - dedicated light sources.

Of course the results presented here are preliminary and further work under the MARS project have to be done. For instance, instabilities due to the accelerating structure, intrabeam scattering and influence of magnetic elements imperfections to the beam emittances will be investigated in the near future. But till now we could not find any serious physical or technical obstacles for this approach.

6 REFERENCES

[1] 10th ICFA Beam Dynamics Panel Workshop on 4th Generation Light Sources, Grenoble, January 1996.

[2] Workshop on Forth Generation Light Sources. Stanford, February 1992, SSRL 92-02.

[3] G.Kulipanov et.al. J.Synchrotron Rad. (1998), in press.

[4] R.E.Rand, Recirculating electron accelerators, Harwood Acedemic Publishers, 1984.

[5] N.A.Vinokurov et al. Nucl. Instr. and Meth. A375 (1996) 403.

[6] Y.U.Jeong, P.Vobly et al. «Free Electron Laser and its Application in Asia» Proc. Of AFEL 97, p.149 (1997).