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CONCEPTUAL DESIGN OF THE RF SYSTEM FOR THE STORAGE RING AND LINAC OF THE NEW LIGHT SOURCE IN THAILAND

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Abstract

The new light source facility in Thailand will be a ring-based light source with the circumference of approximately 300 m and an electron energy of 3 GeV. The target beam emittance is below 1.0 nm rad with a maximum beam current of 300 mA. The injector utilizes a full energy C-band linac with a photocathode RF electron gun. The storage ring RF system is based on a 500 MHz frequency. The EU-HOM damped cavity and the new SPring-8 design TM020 cavity is the choice of the storage ring cavity. The RF power unit for storage ring can either be a high-power klystron feeding all RF cavities or a combination of low power IOTs or solid-state amplifiers feeding each cavity. The high gradient C-band structure is considered as the main accelerating structure for linac. The RF power system for linac will base on klystron and a modular modulator. Details of RF systems options for this new light source project will be presented.

INTRODUCTION

The Siam Photon Source (SPS), the existing machine which is one of two synchrotron machines in South East Asia, has been operating with 1.2 GeV beam energy and ~41 nm rad beam emittance. The new machine has to provide better photon beam characteristics and stay globally competitive for the growing user community in the region. The new facility will be located in the same site as the existing machine at Suranaree University of Technology (SUT). Though it is a new machine, not official namely SPS-II, has some constraints on the size due to the space available and financial reasons. Medium size storage ring with the circumference below 400 m is sufficient to make a beam emittance below 1.0 nm rad and allows more than 20 insertion device (ID) beamlines for the new design. The 3 GeV electron beam energy with maximum beam current at 300 mA is sufficient to serve user community.

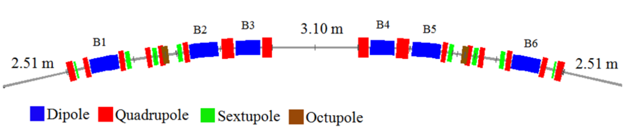

Figure 1: The DTBA cell of SPS-II.

The new storage ring is composed of 14 double triple bend achromat (DTBA) cells [1] (22.95 m/cell) as shown in Fig. 1, which make 321.3 m total ring circumference. Full symmetry requires the ring to have all 14 cells identical. The total number of available straights is 28 (14 long straights with the length of 5.02 m and 14 short straights with the length of 3.10 m in middle of the cell). The new storage ring parameters are summarized in Table 1.

The full-energy C-band linac with the S-band photocathode gun is utilized as an injector of the SPS-II. It is also operated as an electron source for an additional short pulse facility adjacent to the storage ring to generate short and intense radiation pulses for users. The linac can be upgraded in the future to become a free electron laser facility. More importantly, the high brightness electron beam for the short pulse facility can be used for plasma-wakefield acceleration experiment opening a path for SLRI to the novel acceleration research. The schematic of the injector is illustrated in Fig. 2.

Table 1: SPS-II Storage Ring Parameters

Parameters	Value
Energy	3 GeV
Current	300 mA
Lattice	DTBA
Circumference	321.3 m
RF frequency	500.12 MHz
Harmonic number	536
RF voltage	2.2 MV
Emittance ε_{x0}	0.96 nm rad
Nat. energy spread σ_E	0.077%
Nat. chromaticity ξ_x/ξ_y	-64.3/ -77.5
Tune Q_x/ Q_y	34.24/ 12.31
Momentum compaction α_c	3.18×10^{-4}
Nat. bunch length	2.854 mm
Energy loss per turn U_0	577 keV
Full IDs energy loss per turn	1000 keV

STORAGE RING RF SYSTEM

The new storage ring is based on 500 MHz RF system. The potential choices of the RF cavity are the EU-HOM damped cavity [2, 3] and the new SPring-8 design TM020 cavity [4]. The EU-HOM damped cavity is used in the ALBA synchrotron and proved to be successful operation, but the SPring-8 TM020 cavity has only been proved with the prototype properties. Both cavities have almost the same insertion length of 0.5 m. The SPring-8 TM020 cavity has higher shunt impedance of 6.8 MΩ compared to 3.1 MΩ of the EU-HOM damped cavity. The TM020-mode cavity type will be a better solution for the SPS-II storage ring. By timeline of the SPS-II project, the SPring-8 TM020 cavity operational performance should be already tested in the SPring-8-II storage ring.

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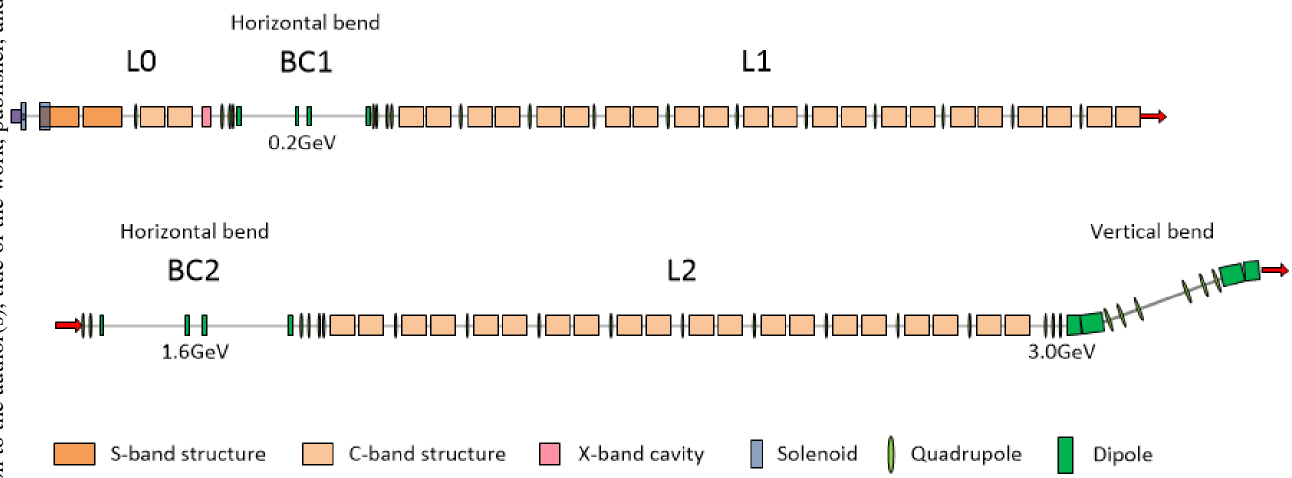

Figure 2: Schematic view of the full-energy linac injector.

The modification has been made to the Spring-8 TM020 cavity to fit the SPS-II storage ring frequency of 500.12 MHz. The cavity diameter is kept at 104 cm and the accelerating gap is set to 18 cm. The cavity length is tuned to obtain the SPS-II TM020 cavity as the geometry shown in Fig. 3. The ideal shunt impedance is 11 MΩ, but it will decrease 7%-20% for the fabricated cavity due to ports and the inner surface treatments. For the extreme case, shunt impedance will be about 9 MΩ. RF properties are listed in Table 2.

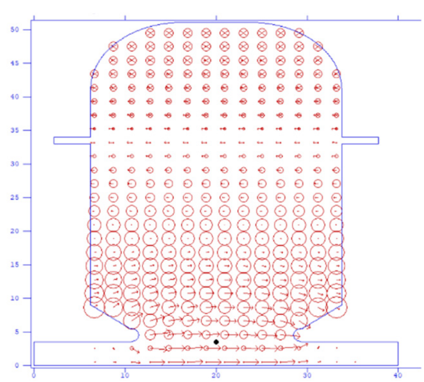
Figure 3: Geometry of the SPS-II TM020 cavity with arrows and circles represent electric and magnetic fields, respectively.

Table 2: RF Properties of the SPS-II TM020 Cavity

Parameters	**Value**
Frequency	500.12 MHz
Unloaded quality factor	57,000
R/Q (definition of $V^2/\omega U$)	196 Ω
Shunt impedance	9 MΩ
Maximum accelerating voltage	900 kV
Insertion length	0.4 m

Four cavities will be installed in one short straight of DTBA cell. The 2.2 MV cavity voltage can be achieved by operating each cavity at 550 kV. With this operation, each cavity requires 34 kW RF power. The first phase operation of SPS-II, with 7-IDs installed, the total energy loss is 807 keV/turn or 242 kW for 300 mA beam current. It means that each cavity will compensate 60.5 kW. Hench, each cavity requires at least 95 kW RF power. For the extreme case with 100% IDs, the energy loss is estimated to be 1.6 MeV/turn or 480 kW. So, each cavity requires at least 154 kW RF power from a transmitter. The operational scenario and the total power needed is listed in Table 3.

In the first phase of the operation each cavity can be supplied using a standalone 125 kW solid-state RF amplifier. This one amplifier per RF station configuration can be used until 50% IDs were added into the ring. Future upgrade can be done by adding the second 125 kW amplifier in each RF station to obtain 250 kW per station using the cavity combiner scheme of ALBA [5, 6]. This can service each cavity for the maximum voltage of 900 kV and 100% IDs.

Table 3: Operational Scenario of the SPS-II TM020 Cavity

Parameters	**7-IDs**		**100% IDs**	
Energy loss (keV)	807		1600	
Beam current (mA)	300		300	
Beam power (kW)	242		480	
No. of cavities	4		4	
RF voltage (MV)	2.2	3.6	2.2	3.6
Over voltage ratio	2.73	4.46	1.38	2.25
R_s (MΩ)	9		9	
Cu losses (kW)	134	360	134	360
Power needed (kW)	376	602	614	840
No. of RF stations	4		4	
No. of transmitters	4	8	8	8
Transmitter power (kW)	125	125	125	125
Power to cavity (kW)	95	151	154	210
Cu losses/cavity (kW)	34	90	34	90
RF power coupling (β)	2.8	1.7	4.6	2.3
Voltage/cavity (kV)	550	900	550	900

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INJECTOR RF SYSTEM

The injector is based on a full-energy C-band linac with a S-band photo cathode gun and two S-band structures in early stage of acceleration as schematic shown in Fig. 2. The C-band system was considered as an appropriate choice for SPS-II linac in term of site size, cost, and efficiency.

There are two possible choices of the photocathode RF gun. The first one is a 1.6-cell S-band BNL/SLAC/UCLA photocathode gun as used at LCLS [7] and MAX-IV. The other choice is the photocathode gun designed at PAL used in the PAL-XFEL injector [8].

The accelerating structures of the linac consists of 44 C-band structures, two S-band structures, and one X-band structures as shown in Fig. 2. The 3-metre length S-band structures will be operated at an acceleration gradient of 20-25 MV/m and the 2-metre length C-band structures will be operated at 35-40 MV/m. The 1-metre length X-band structure will have an acceleration gradient higher than 70 MV/m.

Table 4: Parameters of the C-band Structure

Parameters	Value
Structure type	Quasi-constant gradient
Resonant mode	TM01-2π/3
Frequency	5712 MHz
Average quality factor	9,300
Average group velocity	0.023
Filling time	290 ns
Attenuation constant	0.59
Average shunt impedance	66 MΩ/m
Effective length of acceleration	1.767 m

The good choice for the main accelerating structure is the new simpler disk-loaded C-band accelerating structure developed at Spring-8 [9] under a cheaper scheme linac for the new light source. The design aims to achieve a high acceleration gradient of > 50 MV/m and to withstand higher heat load from running with an RF-pulse repetition frequency of 120 Hz. The structure was manufactured and conditioned at SACLA. The acceleration gradient is reached a value of more than 50.1 MV/m without any serious issues at 120 Hz pulse repetition rate. The acceleration gradient of 41.4 MV/m was achieved from beam operation. The parameters of this structure are listed in Table 4.

The RF systems for the photocathode gun, S-band linac, and C-band linac are separated individually on each system, but the master frequency is taken from the same master oscillator. The whole system for the injector will be based on the S-band frequency of 2856 MHz using the low noise master oscillator. Then the output frequency is distributed and multiplied to get 5712 MHz C-band frequency, and 11.424 GHz X-band frequency.

The RF station will equip with a high power klystron (~50 MW), a solid-state modulator, and a pulse compressor. The RF station will supply RF power to two accelerating structures. One RF unit of this configuration can accelerate electron beam to 144 MeV for C-band system as schematic shown in Fig. 4. There are, in total, 22 RF units of C-band system, two S-band RF units, and one X-band RF unit for the SPS-II injector.

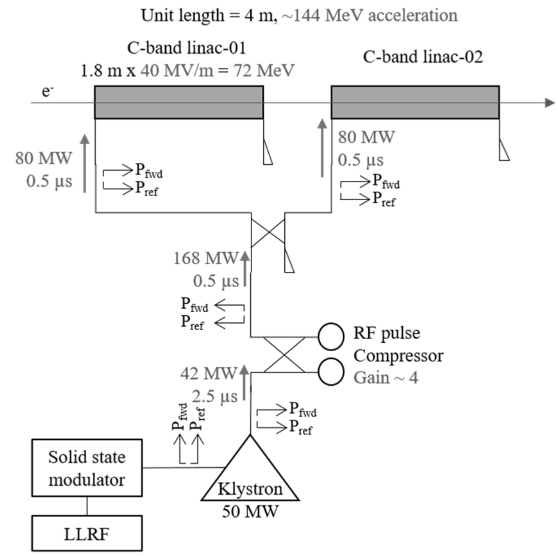

Figure 4: Configuration of the C-band RF unit.

SUMMARY

The SPS-II project will be a ring based light source with the full-energy C-band linac injector. The S-band photocathode gun will be used as an electron source. The simpler disk-loaded C-band structure will be used at an acceleration gradient of 35-40 MV/m. The RF power transmitter for injector is a high power klystron with a solid-state modulator. There are total 25 RF stations for the injector. The 321.3 m storage ring accommodates 14 cells DTBA lattice. The nominal RF voltage is 2.2 MV producing from fours of the TM020-mode cavities. The 125 kW solid-state RF amplifier will be used in four RF stations in the first phase of SPS-II. Later, each RF station will be upgraded to provide 250 kW RF power.

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