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THE NEW DESIGN OF THE RF SYSTEM FOR THE SPS-II LIGHT SOURCE

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Abstract

The new light source facility in Thailand, SPS-II, is a ring-based 3 GeV light source with a circumference of approximately 330 m. The target stored beam current is 300 mA with an emittance of below 1.0 nm rad. The injector has been changed from a full energy linac to a booster injector with 150 MeV linac. The main RF frequency has been reconsidered to a low-frequency range at 119 MHz. Low frequency is chosen with the benefit of low RF voltage for a high RF acceptance together with experience with the present ring RF system of 118 MHz. Details of RF frequency consideration will be discussed. The requirements and details of the RF systems in the booster ring and the storage ring will be presented.

INTRODUCTION

The new light source facility in Thailand, not official namely SPS-II, has been reconsidered to the traditional design after the intensive reviewed scientific and financial aspect. It changed from the full energy linac injection to the full energy booster ring injection. This is different from the previously presented [1]. The new design of the storage ring is composed of 14 double triple bend achromat (DTBA) cells (23.393 m/cell) as shown in Fig. 1, which make 327.5 m total ring circumference [2]. Full symmetry requires the ring to have all 14 cells identical. The booster ring is designed with a FODO lattice with combined function magnets. These two rings will be in the same tunnel with a center ring distance of 3.61 m. The parameters are summarized in Table 1.

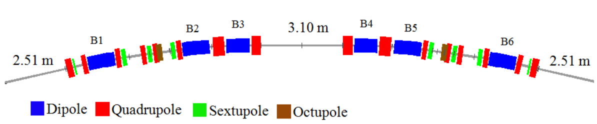

Figure 1: The DTBA cell of the SPS-II.

RF REQUIREMENTS

The main RF frequency has been reconsidered to a low-frequency range at 119 MHz. Low frequency is chosen with the benefit of low RF voltage for a high RF acceptance together with experience with the present ring RF system of 118 MHz. The RF requirement of the storage ring and the booster ring is calculated from the ring parameters to at least overcome Toucheck's lifetime of the ring. The storage ring will be equipped with seven insertion devices (7-IDs) in the first phase of operation. These 7-IDs make the electron

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Table 1: SPS-II Storage Ring and Booster Ring Parameters

Parameters	Storage ring	Booster ring
Energy	3 GeV	3 GeV
Current	300 mA	30 mA
Lattice	DTBA	FODO
Circumference	327.502 m	304.829 m
RF frequency	119 MHz	119 MHz
Harmonic number	130	121
RF voltage	1.5 MV	1.2 MV
Emittance ϵ_{x0}	0.96 nm rad	5.87 nm rad
Nat. energy spread σ_E	0.077 %	0.091 %
Nat. chromaticity ξ_x/ξ_y	-65.6/ -76.7	-23.63/ -10.31
Tune Q_x/Q_y	34.24/ 12.31	14.71/ 5.61
Momentum compaction α_c	3.33×10^{-4}	1.674×10^{-3}
Nat. bunch length	7.48 mm	23.04 mm
Energy loss per turn U_0	577 keV	750 keV
Full IDs energy loss per turn	693 keV	-

beam lost energy 230 keV/turn. The bare ring energy loss is estimated at 580 keV/turn. The full IDs (21-IDs) energy loss is scaled from the 7-IDs. The RF acceptance is set at 4.2% and 1.5% for the storage ring and the booster ring, respectively.

Table 2: RF Requirements of the SPS-II Storage Ring and the Booster Ring

Parameters	Storagr ring 0-IDs	7-IDs	21-IDs	Booster ring
Beam current (mA)		300		30
Energy loss (keV/turn)	580	810	1270	750
Total beam power (kW)	174.0	243.0	381.0	22.5
Number of RF cavity	5	5	6	4
Voltage/cavity (kV)			300	
Total RF voltage (MV)	1.5	1.5	1.8	1.2
Over voltage ratio	2.59	1.85	1.42	1.7
RF acceptance (%)	5.8	4.7	3.7	1.60
Cavity R_{sh} (MΩ)			3.4	
Cu losses/cavity (kW)			26.5	
Total Cu losses (kW)	132.4	132.4	158.8	105.9
Total RF power (kW)	306.4	375.4	539.8	128.4
Power per cavity (kW)	61.3	75.1	90.0	32.1
RF coupling (β)	2.3	2.8	3.4	1.2
No. of RF station	5	5	6	4
No. of RF transmitter	5	5	6	4
Transmitter power (kW)		120		50

The RF acceptance of the SPS-II storage ring for different energy losses are plotted in Fig. 2. It is clearly seen that five cavities, operating at 300 kV, are sufficient for the bare ring

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and the first phase 7-IDs. These fives cavities can support the maximum electron beam energy loss of 905 keV/turn with the 4.2% RF acceptance. This reflects the maximum of 12 IDs to be installed in the storage ring. The sixth RF cavity system can be installed while the ID is being added. With six cavities, the RF acceptance is 3.7% for the full 21-IDs. This makes the beam lifetime limit to the RF voltage instead of the momentum acceptance of the ring. To overcome this limitation, there are two possible solutions; adding the seventh cavity system or operating six cavities at 325 kV. The former is simple but requires preparation of spaces and budget. The latter requires R&D to push the accelerating voltage to the required value. Four cavities can be installed in the long straight of the lattice. So, two long straight sections will be reserved for the main cavity. A maximum of eight cavities can be occupied in the reserved spaces. Adding the seventh cavity system might be the possible solution for the maximum requirement of insertion devices. The RF requirements of both the storage ring and the booster ring are summarized in Table 2.

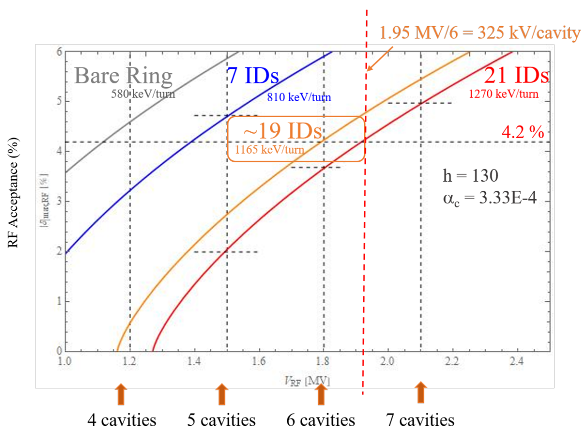

Figure 2: The RF acceptance of the SPS-II storage ring.

RF CAVITY DESIGN

The RF cavity design utilizes the MAX-IV capacitive loaded type cavity [3]. The present 118 MHz RF cavity has also based on the design of the MAX-IV cavity [4, 5]. The MAX-IV cavity was re-optimized to match the 119 MHz and the aperture of the beam duct. The good candidate design has an accelerating gap of 50 mm to obtain the gap voltage of 300 kV. To keep the resonant frequency of 119 MHz, the capacitor plate radius is 114 mm, the cavity inner length is 325.4 mm, while the cavity inner radius and rod radius still are 410 mm and 60 mm of MAX-IV cavity, respectively. The back of the rod is rounded with a radius of 60 mm. The optimization tries to keep most of the original MAX-IV cavity to ease the fabrication process and no prototype is needed. The theoretical shunt impedance of 3.8 MΩ is obtained from this shape, but the practical shunt impedance should be at 3.2 MΩ as experiences from MAX-IV cavities and the present SPS cavity. One-half of the cylindrical symmetric profile is illustrated in Fig. 3. The RF properties are listed in comparison with the present cavity and the MAX-IV cavity in Table 3. The 30 kW RF power transmitter is needed to keep the accelerating voltage at 300 kV.

The study of the longitudinal modes in the cavity was performed with the Superfish code. The results impedance, unloaded, are shown in comparison with the other two cavities in Fig. 4. This indicates the similar behavior of the cavity to the MAX-IV cavity with the lowest longitudinal mode around 400 MHz. The maximum shunt impedance is at a frequency around 1 100 MHz. This is the unloaded mode with no all ports influence. When ports are introduced to the cavity, the quality factor of modes will reduce and result in the reduction of the shunt impedance of modes. The higher-order modes (HOMs) absorber may not be required as the lowest mode frequency is far from the fundamental frequency and it has very small shunt impedance. HOMs couplers were not foreseen in the MAX-IV cavity in the first phase, but two ports on the mantle surface were provided for possible future use. This will be the case for the SPS-II cavity.

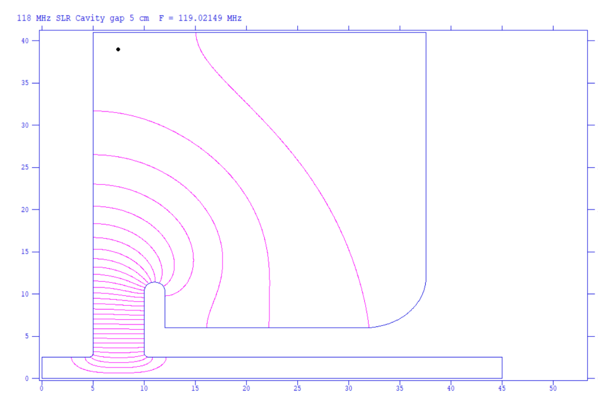

Figure 3: The SPS-II 119 MHz cavity profile.

Table 3: RF Properties of the SPS-II, SPS-I, and MAX-IV RF Cavity

Parameters	SPS-II	SPS-I	MAX-IV
Frequency, MHz	119	118	100
Q_0 (scaled)	20,000	19,000	19,000
R/Q (def. $V^2/\omega U$), Ω	173	136	168
R_{sh}, MΩ	3.4	2.9	3.2
Port diameter, cm	5.0	11.0	5.0
Power for 300 kV, kW	26.5	30.6	28.2

RF STATION CONFIGURATION

The RF requirements in Table 2 indicates that there are a maximum of six RF stations for the full operation of the SPS-II storage ring and four stations for the booster ring. The configuration of the RF station for the ring's cavity consists of the solid-state RF amplifier, circulator, RF switch, amplifier dummy load, and circulator dummy load as illustrated in Fig. 5. The maximum rating of the RF amplifier is 120 kW

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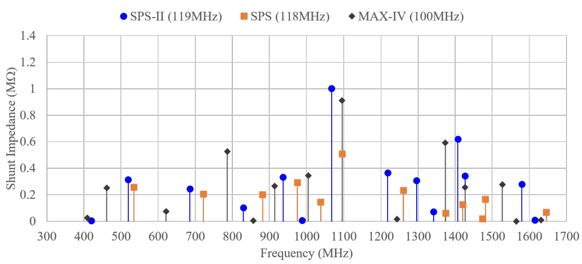

Figure 4: The longitudinal impedance, unloaded, of three cavity designs.

per station and 50 kW per station for storage ring and booster ring, respectively. The LLRF will be a digital platform with an FPGA-based design. There are two LLRF units for the storage ring cavities in which one LLRF unit controls three cavities. One LLRF unit is used for the booster ring cavities. The harmonic cavities will be used for bunch lengthening to prolong the Touschecks lifetime. These cavities will be controlled by one LLRF unit. Figure 6 shows the RF signal distribution from the 119 MHz master oscillator. The linac frequency will be synthesized from the ring frequency for automatic synchronization.

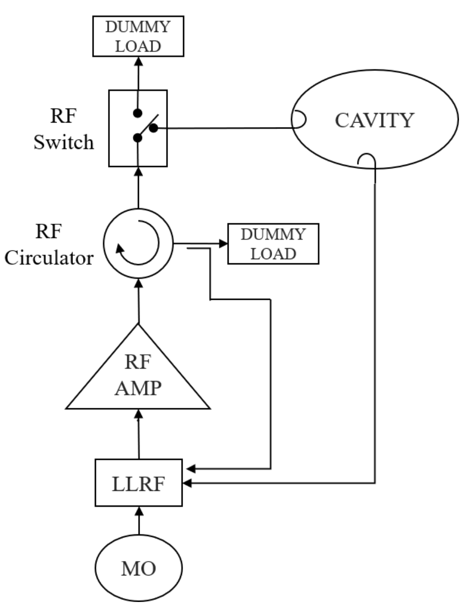

Figure 5: The configuration of RF station.

CONCLUSION

The ring RF system is based on the low-frequency region of the 119 MHz system. Low frequency is chosen with the benefit of low RF voltage for a high RF acceptance together with experience with the present ring RF system. The main 119 MHz RF cavity is designed based on the MAX-IV RF cavity. The RF power of 30 kW is sufficient to maintain the 300 kV accelerating voltage of the cavity. This cavity will be used without an HOMs absorber. There will be six cavities

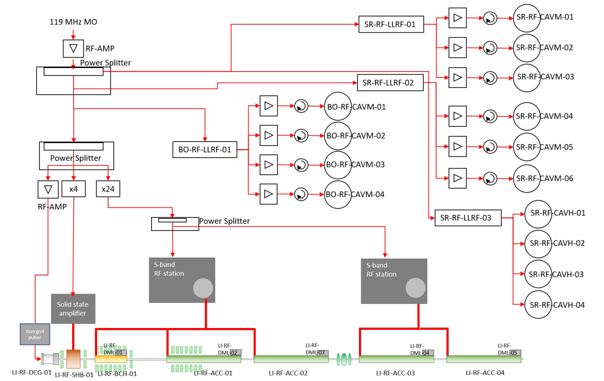

Figure 6: RF frequency distribution diagram.

for the storage ring and four cavities for the booster ring. The 120 kW solid-state RF amplifier will be used for the storage ring RF station while the booster ring requires 50 kW per station. Digital LLRF system based on the FPGA will be utilized for controlling RF systems.

The SPS-II project was officially approved by the cabinet of Thailand in January 2020. The building to accommodate the light source is designed in 2021 and is planned to start construction in 2022. The procurement for machine subsystems will start from 2023 if the covid-19 pandemic is relieved. User service is planned for 2029. The RF system of the ring and linac will mainly purchase from well-known suppliers.

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