ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA078

DESIGN STATUS OF RF SYSTEM FOR THE KOREA 4th GENERATION STORAGE RING

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Abstract

A new fourth-generation storage ring(4GSR) will be built in Ochang, South Korea until 2027. A technical design report of the Korea 4GSR is currently in progress and is expected to be completed in 2023 by PAL. The storage ring has a circumference of 800 m. It has been designed for a maximum current of 400 mA at 4 GeV electron beam energy. A target emittance is 62 pm-rad, 100 times less than PLS-II which is the 3rd generation light source in Korea. The RF system for the Korea 4GSR consists of 10 or more normal conducting cavities, a low-level RF(LLRF) system, a high-power RF(HPRF) system and so on. Additionally, we are planning to install harmonic cavities for Landau damping, on the other hand for improving of beam lifetime and less wake field. In case of the LLRF, we would try to apply new digital feedback control scheme. And the HPRF is taking account of solid-state power amplifier (SSPA). This presentation shows the current status and plans of the RF system for the Korea 4GSR.

OVERVIEW OF KOERA-4GSR PROJECT

The Korea 4GSR project is scheduled to start in July 2021 and continue until 2027. The total budget is approximately 1 trillion won, and the site will be located in Ochang, Chungcheongbuk-do, about 100 km away from Seoul, with a total area of 540,000 m^2.

Table 1 shows the Korea 4GSR main parameters, with the target emittance being calculated at 62 pm-rad. The initial construction will involve 10 beamlines, with plans to construct 40 or more beamlines ultimately. The injector LINAC will use a photocathode gun to generate and accelerate the electron bunch to 200 MeV, which will be transferred to the booster for further acceleration before being sent to the storage ring, where the electron beam will be accelerated from 200 MeV to 4 GeV. Both the booster and storage ring will be installed in the same tunnel. The circumference of the storage ring will be 799.279 m, while the circumference of the booster will be 772.893 m. The lattice of the storage ring will be designed using the Hybrid 7 Bend Achromat(H7BA).

BOOSTER RING RF SYSTEM

Table 2 shows the Booster RF system parameters. The beam current for the single-bunch mode in the booster is 2 mA, and the RF frequency is 499.594 MHz. The injection energy is 200 MeV, and the extraction energy is 4 GeV. The energy loss per turn at 4 GeV is 1.57 MeV, and the required acceleration voltage is 3.0 MV.

Table 1: Korea 4GSR Main Parameters

Parameters	Value
Energy [GeV]	4
Storage ring Circumference [m]	799.297
Booster ring Circumference [m]	772.893
Emittance [pm-rad]	62
Tunes (H, V)	68.10, 23.18
Natural chromaticity (H, V)	-109.6, -84.7
Horizontal Damping partition	1.84
Momentum compaction	0.78×10^{-4}
Energy spread(σ_δ)	1.26×10^{-3}
Energy loss per turn [MeV] (only Bending)	1.097
Beam Current [mA]	400
Bunch length(σ_s) [mm]	4.058 / 16.232 (with 3rd harmonic cavity)
Number of Beamline	25(ID) 28(2 T Bend)

To apply this acceleration voltage, various types of cavities were compared, and the 5-cell PETRA type cavity [1], which is advantageous in terms of space and cost in the booster ring, was chosen. To apply a 3.0 MV acceleration voltage, 3 sets of 5-cell cavities are required, and the required power per unit is 34.41 kW at the power coupler.

Figure 1 shows the energy ramping of the booster ring. The ramping frequency is 2 Hz, and the ramp-up time is 250 ms, while the ramp-down time is 150 ms. To meet these requirements, the specifications of the Low-Level RF (LLRF) in the booster ring are as shown in Table 3. We plan to manufacture a stand-alone LLRF system based on RFSoC.

To supply 34.41 kW at the coupler, the high-power RF power amplifier (HPRF) is selected 80 kW Solid State Power Amplifier (SSPA), considering approximately 6% waveguide and circulator power losses. The operation of the SSPA is based on operating the SSPA at a 50% level.

* Work supported by the Korean Government MSIT (Multipurpose Synchrotron Radiation Construction Project).
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Table 2: Booster Ring RF Parameters

Parameters	Value
Beam Current [mA]	2
RF Frequency [MHz]	499.594
Energy [GeV]	0.2 – 4.0
Turn by Energy loss [MeV]	1.57
Accelerating Voltage [MV]	3.0
Number of cavities	3
Coupling beta	~ 1.10
Required power to coupler per cavity [kW]	34.41
Rated power of HPRF / unit [kW]	80

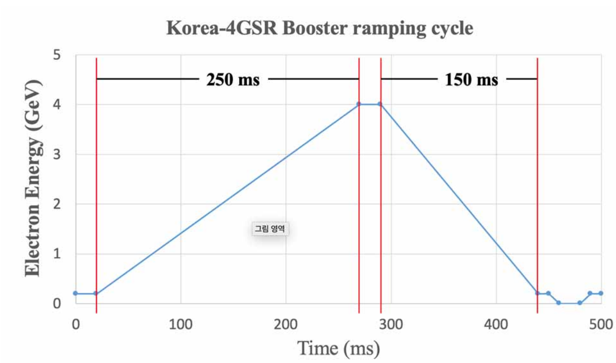

Figure 1: Korea 4GSR Booster Ramping Cycle

Table 3: Parameters of Booster LLRF System

Parameters	Value
RF Frequency [MHz]	499.594 ± 0.100
RMS jitter (1 Hz to 1 MHz Offset BW) [ps]	< 0.5
RF amplitude Stability (RMS)	< 0.2 %
RF Phase Stability (RMS) [deg]	< 0.2
Frequency Tuning Range [kHz]	> ± 100
Frequency Resolution [Hz]	< 1

STORAGE RING RF SYSTEM

Table 4 shows the specifications of the storage ring RF system. The maximum beam current is 400 mA, and the frequency is 499.594 MHz, the same as the booster. The total energy loss due to bending magnets, insertion devices, and other devices is 1.88 MeV, and the required accelerating voltage is 3.5 MV.

To obtain this accelerating voltage, a normal conducting cavity was selected instead of superconducting cavity to minimize downtime due to unstable operation and repairs, with the EU-HOM damped type [2] being considered as it has been verified for HOM removal.

Table 4: Storage Ring RF Parameters

Parameters	Value
Beam Current [mA]	400
RF Frequency [MHz]	499.594
Turn by Total Energy loss [MeV] (Bending, ID, others)	1.88
Accelerating Voltage [MV]	3.5
Number of cavities	10
Optimal Coupling beta	4.5
Required power to coupler per cavity [kW]	98.57
Rated power of HPRF / unit [kW]	150

To meet the required accelerating voltage, at least 10 EU-HOM damped cavities are needed. Assuming 10 cavities are installed, and the coupling beta is set to 4.5, the required RF power at the coupler is 98.57 kW.

The specifications for the required LLRF system for stable RF power supply are shown in Table 5. The RF amplitude stability is set to be below 0.1%, and the RF phase stability to be below 0.1 degrees. The tuning range should be at least 100 kHz, and the frequency resolution should be below 1 Hz.

Table 5: Parameters of Storage Ring LLRF System

Parameters	Value
RF Frequency [MHz]	499.594
Local Oscillator Frequency (@ 20 dBm)	499.594
$Q_L(Q_{ext})$	527(6444)
Maximum Frequency Range [MHz]	3.0874
Cavity Frequency Control Range [kHz]	>± 300
RF amplitude Stability (RMS)	< 0.1 %
RF Phase Stability (RMS) [deg]	< 0.1
Frequency Tuning Range [kHz]	> ± 100
Frequency Resolution [Hz]	< 1

Figure 2 shows the master oscillator and distribution system. The green, blue and red boxes are master oscillator, distribution amplifier and low drift and jitter optical RF signal transfer systems, respectively. The plan is to install the master oscillator in the main RF building control room and distribute it to the storage ring, booster ring, and LINAC. The time delay caused by the storage ring's large size will be addressed during the system configuration.

For HPRF, an SSPA was chosen taking into account the installation space and maintenance after installation.

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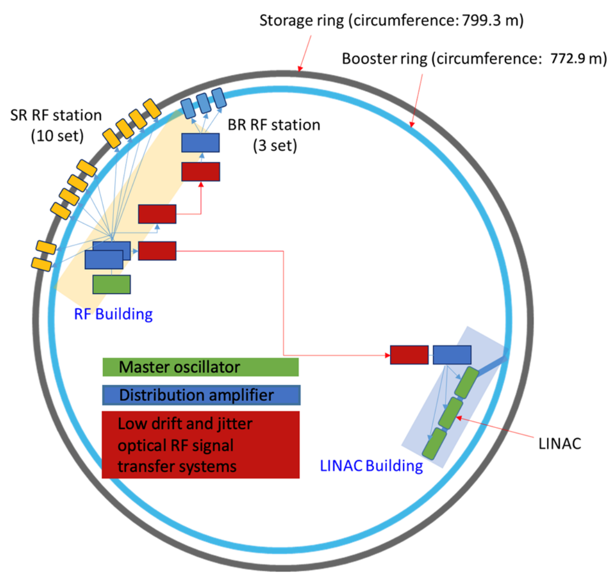

Figure 2: Master Oscillator and Distribution system

Table 6 shows the required RF power calculated assuming 10 EU-HOM cavities are used. 98.57 kW is required at the coupler and taking into account approximately 10% waveguide and circulator losses, 108.57 kW is required at the output of the SSPA. Assuming the SSPA is operated at 73% of its total capacity, a 150 kW SSPA is required.

Table 6: Storage Ring Calculated HPRF Power

Parameters	**Value**
Required accelerating voltage per cavity [MV]	0.35
Wall loss power per cavity [kW]	18.01
Beam loading power per cavity [kW]	75.11
Power loss at HOM absorbers [kW]	5
Required power to coupler per cavity [kW]	98.57
Transmission line loss per cavity [kW]	10
Reflected power per cavity [kW]	0.44
Required output power of HPRF [kW]	108.57
Rated power of HPRF [kW]	150

The specifications for the required SSPA for stable RF power supply are shown in Table 7. A waveguide type combiner is being considered for combining the power output of the modules.

Table 7: Specification of Storage Ring SSPA

Parameters	**Value**
RF rating	500 MHz cw, BW ≥ ± 1 MHz
In / Out Power	0 dBm Max / > 150 kW @P1 dB
Gain Flatness	0.5 dB within BW
Output Power Stability	0.5 % Vp-p
Phase Variation by power	3° / dB
Phase Stability	0.5° @ rated power
Efficiency	> 50 % @ P1dB
Input/output Z	50 **Ω**
Harmonics	< -36 dBc
Spurious	< -70 dBc
RF Ports	In : N-type / Out : WR1800
VSWR	< 2

PLANS

The Korea 4GSR project is currently underway, with specifications for the RF system components being finalized in order to complete the project by 2027. Once the specifications are confirmed, prototypes of the RF devices will be produced and their performance will be verified to test their suitability for the Korea 4GSR project. The production of the final products will also be carried out concurrently. To conduct prototype testing, the Pohang Accelerator Laboratory is currently establishing a testing space and preparing the necessary systems for testing. Afterward, based on the experience gained from building the testing facility at the Pohang Accelerator Laboratory, a testing bench will be set up in the Ochang site to test all RF equipment and systems.

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