COMMISSIONING OF THE SLRI STORAGE RING SECOND RF SYSTEM

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ABSTRACT

The old RF cavity in storage ring of SIAM Photon Source (SPS), the 1.2 GeV second generation synchrotron light source in Thailand, has been pushed to its maximum capability to compensate electron energy lost in the storage ring. This energy lost effect from two additional insertion devices, which have been installed in SPS storage ring during June to August 2013. The new RF system has been plan since 2012, but with some technical and procurement difficulty the new system was successfully commissioning and running in August 2016. The installation, acceptance testing, conditioning and commissioning results of the new RF cavity, RF high power transmitter and low level RF system will be presented.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) has operated the SPS since it opened for user service in 2003. The 2.4 T multipole wiggler and the 6.5 T wavelength shifter was installed in SPS ring during June to August 2013 [1]. Electron traverses these magnets losing more energy to produce a higher energy x-rays for user. This is beyond a capability of the existing RF system. The second RF system has been planned to strengthen an energy compensation [2]. Two systems will further be used together for the high brightness x-rays beam project.

The Second RF System

The second RF system is separated from the existing system. Both systems uses the same master oscillator. The RF signal from the master oscillator is connected to the digital low level RF system (LLRF). The controlled RF signal is fed to a solid-state RF amplifier module in the RF transmitter. The high-power RF signal is connected to a circulator before feeding to the RF cavity through a power coupler. The measured signals of a transmitted and a reflected RF power are fed back to the LLRF. The pickup signals from the cavity are also sent to the LLRF for controlling amplitude and phase of the accelerating voltage. The system is illustrated in Fig. 1.

The RF Cavity

The new RF cavity shape has adapted the MAX-IV RF cavity shape [3]. Changing some dimensions makes its resonant frequency of 118 MHz suitable for SLRI. The SLRI cavity has a bigger beam aperture, which reflects lower shunt impedance. The decision was made based on the compatibility with the existing vacuum chamber and to avoid an instability from a wakefield effects. The properties of the new SLRI RF cavity compare to the MAX-IV cavity are listed in Table 1.

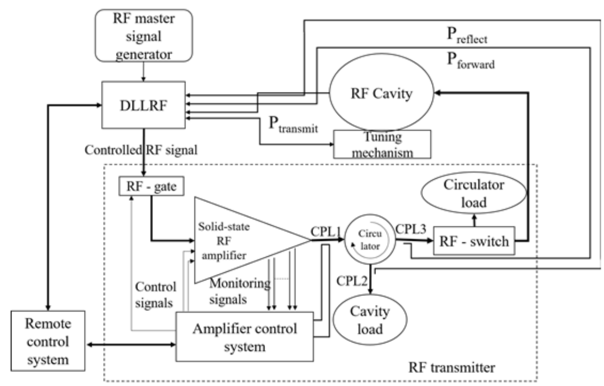

Figure 1: The Second RF system diagram.

Table 1: Properties of RF Cavities

Properties	SLRI cavity	MAX-IV cavity
Frequency [MHz]	118	100
Beam aperture radius [mm]	55	25
Cavity radius [mm]	410	410
Accelerating gap [mm]	50	50
Insertion length [mm]	490	500
Cavity voltage [kV]	300	300
Shunt impedance (V^2/P) [MΩ]	3.1	3.5
Unloaded quality factor (Q_0)	19000	20000

The RF Transmitter

The high-power RF amplifier is utilised a solid-state amplifier technology. The maximum output power is 80 kW with the fluctuation is less than 1% rms. The frequency range is 118±1 MHz. The amplifier was designed to run continuously at a reduced power when 10% of transistors has symmetrical broken (not from the same sub-module) instead of shutting down the operation. This will help preventing a beam dump from a transistor fault in an RF amplifier modules.

The Low-Level RF System

The new low-level RF (LLRF) was designed based on a digital system to obtain a high flexible operation. The LLRF system is operated with the amplitude stability is less than 0.5% rms and the phase stability is less than ±0.5 degree. The phase control is in the range of ±180 degree with the dynamic range is higher than

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20 dB. It will be easy for synchronizing operation with the existing RF system as the old system is also a digital system.

INSTALLATION

The installation of the second RF system was done during June to August 2016. The location of the second RF cavity is at the upstream of the U60 undulator as illustrated in Fig. 2. The detailed schematic and a beam pipe aperture radius is shown in Fig. 3. To avoid a wakefield effects, there are tapered chambers for smoothing out a transition from a race-track cross-section of a vacuum chamber to a circular cross-section of a cavity.

Some activities were done during January to March 2016 such as the installation of a new 500 kVA transformer, water cooling piping, electricity and RF grounding preparation, and some signal and control cabling.

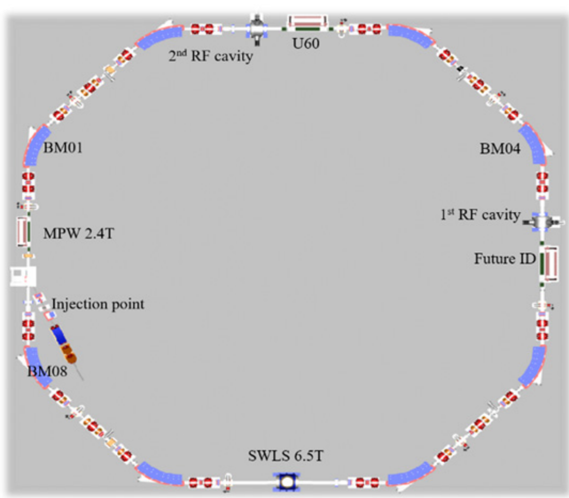

Figure 2: Location of the second RF cavity.

Installation of the solid-state high power RF amplifier, circulator, dummy loads, and the digital LLRF system was done by manufactures staff. The installation of the RF cavity, the RF waveguides and cables, and the water cooling systems for cavity and RF amplifier was done by SLRI staff. After installation and vacuum processing, the base pressure of the new RF cavity section reached 10^{-10} Torr.

ACCEPTANCE TEST OF SYSTEM

The acceptance test of the RF amplifier was done by delivering the amplified output power to a dummy load, which is connected to an RF switch as in Fig. 1. The measured RF leak at all connection in the system is under a safety standard level. The discrepancy output gain of the amplifier at 117 MHz and 119 MHz with 118 MHz gain is -0.16 dB and -0.31 dB, respectively. The maximum output power at 118 MHz is 80.2 kW from the input of 1.2 dB. This 80 kW power was applied to a dummy load for the 24 hours acceptance test. The redundancy performance test was done by taking 16 transistors out of total 160 transistors and continue running the amplifier with a reduced power for 24 hours.

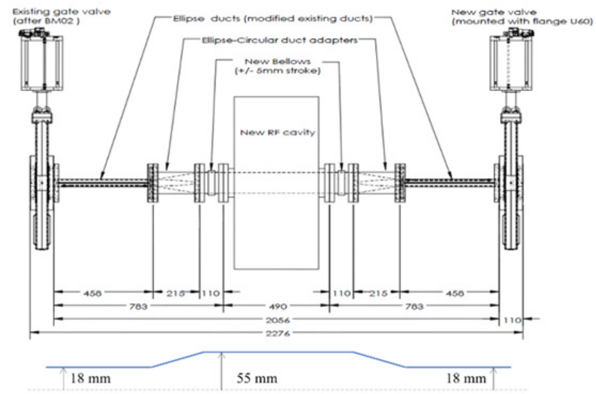

Figure 3: Detailed schematic layout of the new RF cavity.

The LLRF system test was done by performing a functional test of the system. The interlocks and errors handling performance test was also done. The amplitude and phase stability performance was tested by controlling the RF amplifier to deliver the RF power to the cavity and closed-loop control a cavity voltage, without an electron beam loading, at 125 kV for 15 hours. The stability is ±0.009% rms and ±0.012 degree rms for amplitude and phase, respectively.

RF Cavity Conditioning

The beta coupling of the RF cavity was set to approximately 1 for a high-power conditioning. The measured loaded quality factor is 10400, which correspond to Q_0 of 21840. The tuner range of a cavity is 118±0.6 MHz. The pickup probe coupling was adjusted to -40 dB. The leak rate and the RGA measurement is under specification.

The RF cavity was maintained an operation with a water cooling temperature at 42 ºC. The RF cavity was carefully conditioned with a low power to avoid a possible damage on the inner surface of a cavity. The RF power was slowly increased when the vacuum pressure inside the cavity was stable. The RF conditioning was performed in both pulsed mode and continuous mode. It should be performed continuously. The conditioning process completed in 12 days to make the cavity is capable of handling 30 kW RF power, which correspond to an accelerating voltage of approximately 300 kV. The final step is letting the cavity run at 30 kW power for 12 hours without any trips or faults.

The multipacting has been observed at the RF power of 1.5-1.6 kW, 2.8-3.0 kW,4.8-5.0 kW, 9.8-10.0 kW, and 14-16 kW. These multipacting points were carefully treated by applying RF power at that level in both pulse and continuous mode and let a cavity cured itself. Vacuum pressure and reflected power interlocks should be monitored during the treatment. The multipacting at the high-power points had less effect on cavity pressure

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after a treatment, but the effect remained at the low power points. The treatment will recommence after letting a cavity run with electron beam for a certain time.

COMMISSIONING WITH BEAM

The beta coupling of the cavity was adjusted to 2.0 by rotating a coupling loop of the power coupler. The loaded quality factor decreases to 7130 and 10% of incident power reflect to the circulator. After a vacuum baking process, the cavity was conditioned up to only 190 kV due to the schedule time and the radiation level safety limit.

The existing RF cavity was detuned to approximately -300 kHz off the resonant frequency to avoid a wakefield and an instabilities effects. At this position, the induced gap voltage is approximately 3 kV with a 150 mA electron beam at 1.2 GeV.

The new RF cavity was operated at 175 kV whilst the old cavity was detuned during an electron beam commissioning. The radiation level was monitored to be under the safety limit. The objective of a commissioning was to restore the operational parameters of the SPS storage ring before a shutdown, with the operation of the wavelength shifter at 4.0 T and the wiggler at 2.2 T.

Electron beam could be stored in storage ring at the first injection, but instability was observed in the beam profiles. There was an unstable beam size in both vertical and horizontal, which was detected by a visible light beam size monitor system. It was also appeared in betatron tune measurement spectrums, with a strange peak distribution. These are illustrated in Fig. 4.

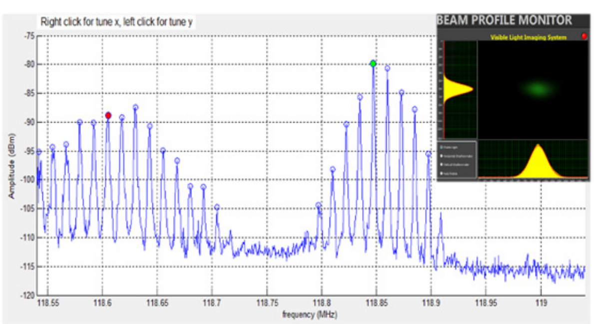

Figure 4: The unstable beam size and betatron tune spectrums.

The unstable beam size was later solved by adjusting a close-loop gain of the LLRF system. The close-loop gain of the LLRF was first set to operate the cavity system without a beam loading. With a beam loading the close-loop gain cannot control a cavity voltage to be within a small fluctuation. It was 175±10 kV at the first beam in the ring. The cavity voltage was later controlled at 175±0.5 kV after the loop gain was adjusted to a suitable value. The electron beam was stable and the betatron tune spectrums were as normal as shown in Fig. 5.

The commissioning was expanded to cover the maximum operation of insertion devices, which is at 2.2 T wiggler and 6.5 T wavelength shifter. Electron beam could be stored in the ring, but the lifetime was not as expected. It was stopped increasing with the RF cavity voltage at a certain value. This was affected by a non-linear dynamics of insertion devices, especially the wiggler [4].

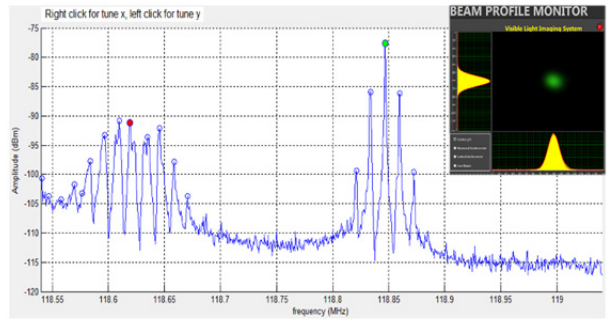

Figure 5: The stable beam and betatron tune spectrums.

CONCLUSION

The second RF cavity system was successful installed and commissioned during June to August 2016. The RF cavity was design based on the MAX-IV RF cavity. It is supplied the RF power from the 80kW solid-state RF amplifier with a digital LLRF system. The cavity was conditioned to handle 30 kW power, which corresponds to approximately 300 kV accelerating voltage. The system was successful commissioned with a 150 mA electron beam at 1.2 GeV. The beam lifetime is improved as expected, but there is a non-linear dynamics of insertion devices which limits the improvement. This will further be investigated and treated.

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