BEAM COMMISSIONING SUPERCONDUCTING RF CAVITIES FOR PLS-II UPGRADE

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Abstract

Two superconducting RF cavities were commissioned with electron beam at PLS-II, which is upgraded machine from PLS with 3 GeV, 20 insertion devices, and now on user service. These SRF cavities have been prepared during last 3 years. Each cavity was tested with higher than 2 MV accelerating voltage and 150 kW continuous SW power after installation at storage ring. PLS-II is on user operation with topup 150 mA beam current now, and on the way of beam current improvement up to 400mA, by synchrotron conditioning beam chamber and in-vacuum undulators. Upto 200 mA beam current no beam instability from the higher order modes is observed. With top-up mode operation, the errors of amplitude of amplitude and phase are recorded as 0.3% and 0.2 degree peak to peak, respectively during one day. Successful PLS-II upgrade with hardware and its designed performance will be declared at the end of 1st half user run in 2013.

INTRODUCTION

PLS-II was commissioned with 5 normal conducting cavities up to 150 mA with energy, 3 GeV during July to December in 2011. Then synchrotron beam started to provide users by normal conducting RF (hereinafter NRF) cavities with 100mA beam, decay-mode from March 2012. One 500 MHz superconducting RF (hereinafter SRF) cavity was installed with replacement of all NC cavities in September 2012. Through one months beam commissioning, user beam was provided 100-150 mA with gradual cavity & window vacuum conditioning time to time. Maximum beam current with one SRF cavity was achieved 200 mA with 250 kW forward RF power and 1.85 MV accelerating voltage. During the first SRF phase, a lot of machine faults were encountered mainly from malfunction of He refrigerator, window & cavity vacuum bursts and also bugs from LLRF. The 2nd SRF cavity, shown in Figure 1, was then added in tunnel last February and was commissioned together with the 1st one. Two SRF cavities' performance shows more stable than that of single SRF cavity. The detail commissioning performance is described following section.

BEAM COMMISSIONING STORAGE RING AND 1st USER SERVICE WITH NRF CAVITIES

Due to the long delivery of cryomodules and helium refrigerator, the setup of SRF system in storage ring couldn't be matched to the other systems so that the upgraded PLS-II was forced to be operated with NRF cavities during first one year including storage ring beam commissioning and user service, August 2011 - July 2012. Each NRF cavity provided about 60 kW forward power and 450 kV accelerating voltage, the maximum beam current for machine study was recorded as 150 mA. The new 300 kW class Klystron amplifiers and high voltage power supplies manufactured by Thales and Thomson, respectively serve to NRF cavities via WR1800 wave guides. Also newly developed digital LLRF [1] with JLab's collaboration was adopted to optimize hard- & soft-wares. Although the NRF performance was big enough for 150 mA beam current, only 100 mA user beam was forced to provide due to orbit instability mainly from NRF cavities. For temporarily operating NRF cavities, the fine-controllable water temperature system was not installed. But, RF performance was good enough under 100 mA, like amplitude error ΔV/V <0.2%, phase error <0.1 degree.

Figure 1: Two SRF modules in tunnel.

COMMISSIONING SRF CAVITIES WITHOUT AND WITH BEAM

The performance of each cavity and window was confirmed through cavity vertical test and windows test & conditioning before integration to cryomodules [2]. Module cryogenic and tuner performances were also confirmed through the factory acceptance tests. RF window and cavity were conditioned with several different pulses of which width, repetition rate and intensity during 30 hours on-resonance TW power and 15 hours off-resonance SW power before beam commissioning at tunnel. That was also processed with similar manner at test-pit to confirm RF performance. Figure 2 shows the last moment of pulse conditioning and RF power commissioning at test-pit. The special designed power controller was equiped to LLRF to protect ceramic

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window by monitoring window vacuum pressure during pulse conditioning. The conditioning was done by open loop LLRF to confirm the safety of cavity and window by human's intervention. The primary RF parameters, measured are shown in Table 1 and Figure 3.

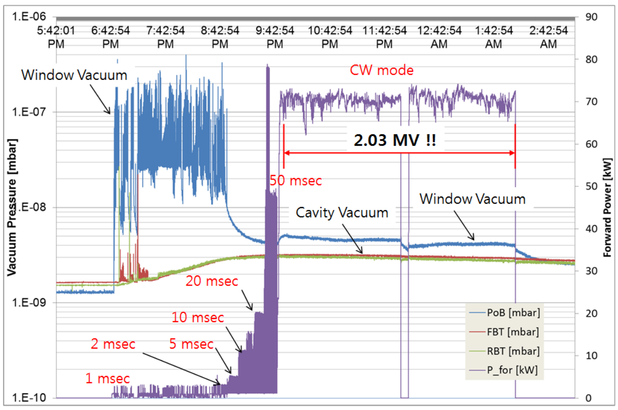

Figure 2: Vacuum pressure and forward RF power during commissioning 1st SRF module by RF power only.

Table 1: Measured RF Parameters

Parameter	Module 2	Module 3
Qext	1.7×10^5	1.5×10^5
Q0 @2MV	7.5×10^8	1.1×10^9
Max Vacc [MV]	2.35	2.40
Max. SW Power @window [kW]	150	150

The initial beam store with 1st SRF cavity was realized easily within 2-3 hours' trial. Then beam current increased up to 170 mA with beam conditioning SRF system and storage ring vacuum chamber. SRF system and storage ring was optimized for user beam operation during 4 weeks. Those beam commissioning and machine optimization were done happily. After that, we fronted a lot of troubles during 10 weeks user shifts. Every RF sub-systems provided minor and severe faults, then resulted to quite low beamline availability as low as 70%. There were many vacuum bursts at window and sometime beam downstream of cavity and several times cavity heating due to mis-control of RF power from LLRF and HPRF at the moment of power trip from storage ring interlock signals. Liquid He transferline was leaked, resulted to 7 days' no user beam service and another 5 days' were lost from 4 times He refrigerator faults from unstable public electric powers. Something good was that we didn't observe any arc, quench and multipacting at SRF cavity. All those trouble, mentioned above, were cleared by January and February 2013 improvements. The control logics of He refrigerator and its compressors were improved to neglect a moment unstable electric power about 20%, and also an uninterrupted power supply (UPS) was equipped to He Refrigerator. The direct transfer of interlock signals from cryomodule to HPRF was replaced to semiconductor type switches, instead of relays. The redundant window protection system, provided by cavity vendor, was removed and interlock logic from LLRF was modified.

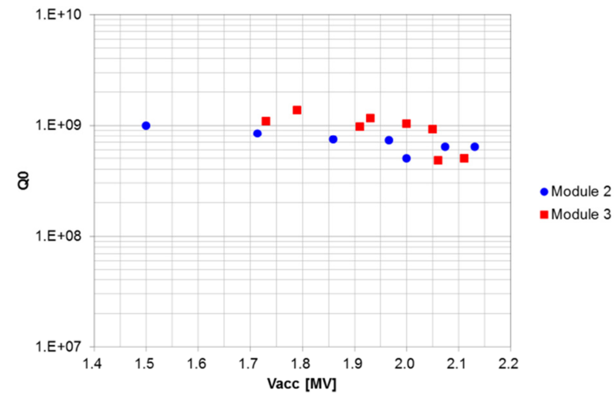

Figure 3: Measured Q0 with accelerating voltage.

As shown in Figure 4 which was a typical RF performance with 1st SRF cavity at topup operation, RF performances also could not met to PLS-II specification which stabilities of amplitude and phase are 0.3% and 0.3 degree.

Figure 4: RF stability with 1st SRF cavity: middle-amplitude ($\Delta V/V \sim 0.4\%$), lower-phase ($\Delta\Phi/\Phi \sim 0.5\ ^{o}$).

The 2nd SRF cavity was added in tunnel on last January then commissioned with beam with similar pre- and post- procedures, only exception that RF performance test at test-pit was skipped in order to save time for machine optimization. Its performance is similar with that of 1st cavity as shown in Table 1 and Figure 3.

BEAM COMMISSIONING WITH TWO SRF CAVITIES AND USER OPERATION

Two SRF cavities provide very stable accelerating voltage to the beam and operation stability so that beam current goes to 200 mA easily, compared to one cavity operation. But PLS-II storage ring and beamlines are on a new road after PLS-II upgrade, which PLS-II never have

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gone to higher than 200 mA. Still the RF's contribution to beam dump is major portion, but it is the reasonable level.

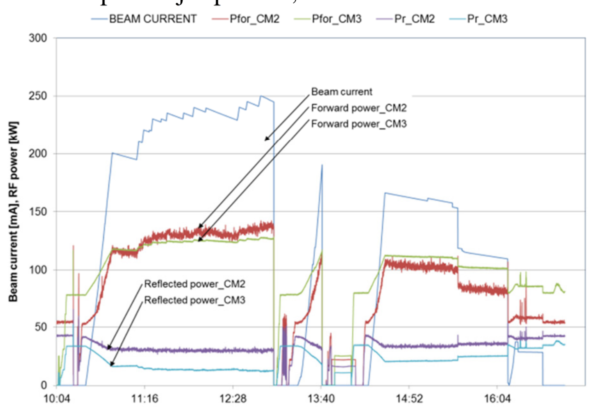

Figure 5: Short history of beam commissioning with two SRF cavities.

We tried to store beam up to 250 mA, but no more trial because it take time to condition and optimize vacuum chamber and beamline components for higher beam current. Faults data which are numerical data and signal analysis from spectrum analyser and oscilloscope are collected by various kinds of artificial interlocks and faults in order to define exact faults diagnosis of SRF cavity. During 4 weeks beam commissioning, no severe cavity abnormality such as multipacting, field emission and quench are observed. Only one arc was detected at window. But several vacuum bursts were happened during trial of 250 mA beam current.

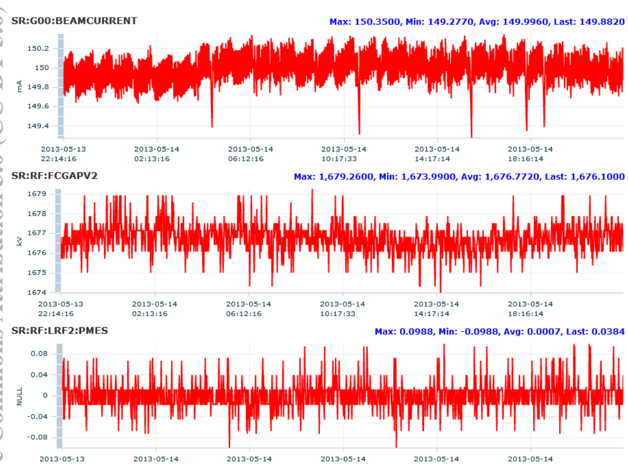

Figure 6: SRF stability with two cavities; middle-amplitude (ΔV/V ~0.3%), lower-phase (ΔΦ~0.2 ^{o}).

The first user run with two SRF cavities started with topup mode, beam current 125 mA, which is much lower beam current than design, to confirm machine stability and robustness at each steps. Then PLS-II provides synchrotron beam with 150 mA from May. From now on, beam current will increase 10 mA step at every start of user run until 200 mA. SRF stability at 150 mA topup mode is shown in Figure 6.

The present operation statistics with SRF cavities can't provide significant meanings just with 18 weeks operation. The first 10 weeks user beam service with one SRF cavity in November-December 2012 was near disaster. But the late 8 weeks operation with two SRF cavities has shown big progress. It would be comparable to the experienced other synchrotron machines. During 4 user-runs 8 weeks, RF trip is 6 times out of total 17 beam dumps. The average down time per RF trip is about 60 minutes. The good thing is that SRF cryomodule's contribution is only 2 times, less than 2 hours down time.

The achievement would be from partial warming up and pulse conditioning cavities and windows before every beginning of user runs. With these processing the cavity and window vacuum pressures can be kept under threshold of vacuum burst of PLS-II cavities as shown in Figure 7. The processing interval would be expected to become longer by time to time with beam conditioning.

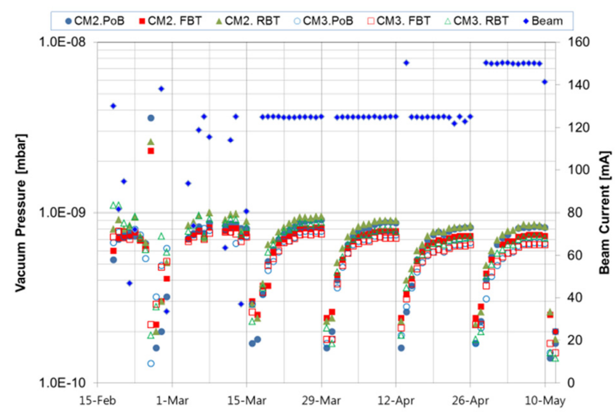

Figure 7: Vacuum pressure of windows (PoB) & cavities (RBT, FBT) and beam current.

Now we start analysis what stability of SRF parameters would affect beam stability and will try to improve system configuration and operation optimization to produce better synchrotron radiation.

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