STRATEGY TOWARDS NON-INTERRUPTED OPERATION OF SUPERCONDUCTING RADIO FREQUENCY MODULES AT NSRRC

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Abstract

Two modern 3rd generation light sources, the well-developed 1.5-GeV Taiwan Light Source (TLS) and the newly commissioned 3-GeV Taiwan Photon Source (TPS), are now both in routine operation at the National Synchrotron Radiation Research Center (NSRRC). Both storage rings are powered by superconducting radio-frequency (SRF) modules, one of the CESR-type for the TLS since the end of 2004 and two modules of the KEKB-type for the TPS since summer of 2014. Thanks to continuous improvements, the operational reliability of the SRF modules at NSRRC is now even better in comparison with the best operation record of room temperature cavities ever achieved at TLS from 1992 to 2004. To gain this long term reliability and availability of SRF modules for maximum available user beam time under the demanding requirements of high RF power operation, is a continuing operational challenge. This is especially true for the SRF modules operating currently at a forward RF power of more than 150-kW each but soon expected to reach 200-kW. Here we report our strategy and current status to guarantee highly reliable SRF operation and to minimize interruptions of SRF operation due to annual maintenance or malfunction of the cryogenic plant.

INTRODUCTION

Two major concerns caution the application of SRF technology for synchrotron radiation light sources even considering its superior features of stability with a high electron beam current. One concern is focused on operational reliability, e.g. due to RF trips every so often, and the other concern comes from the general marginal operational life expectancy of less than 10 years. Both issues are very serious from an accelerator operation point of view. Multipacting in the high power input coupler of a SRF module due to gas condensation impacts seriously any desire for highly reliable operation of the SRF modules. In addition, thermal fatigue of indium vacuum seals for the niobium cavities may develop leaks after many thermal cycles and prevent operational availability of the SRF modules.

Condensation of residual gases on the cold surfaces of the power coupler and cavity cells is always present since their cooling down. Gas condensation depends strongly on the out-gassing rate of the power coupler compared to the pumping speed of the cavity vacuum system. With an increase of beam current, and delivered RF power, the operational SRF modules may encounter serious multipacting causing, the interlock protection to be activated to avoid permanent damage of the power coupler. Consequently, the SRF operation is interrupted. That is the major obstacle to improve the operational reliability of SRF modules. Applying traditional RF processing to the SRF module can mitigate the multipacting but may not be the ideal solution. Applying both partial and full thermal cycling becomes the ultimate process to correct this operational conundrum, yet this process is required within shorter and shorter intervals with the increasing operational RF power.

Two major reasons can enforce a thermal cycling of the SRF module, either due to the release of condensed gas or due to maintenance or fault of the cryogenic plant. An annual maintenance of the compressor is unavoidable. A full thermal cycling of a SRF module is very costly, not to mention a diminished operational life expectancy, a risky recovery, time-consuming and high demand on manpower. We will report here our strategy to improve the reliability and availability of SRF modules and will discuss our operational experience.

BACKGROUND OF SRF OPERATION AT NSRRC

Both, the Taiwan Light Source (TLS) and the Taiwan Photon Source (TPS) are currently in operation to serve experimenters with synchrotron radiation. They are powered by 500-MHz SRF modules, one of the CESR-type (named S1) for the TLS since 2005, and two KEKB-type modules (named #2 and #3) at the TPS since 2015. More technical details for these SRF modules operated at NSRRC can be found elsewhere [1-3].

The operational challenge of an SRF module at TLS is relative straight forward, because its maximum forward RF power for routine SRF operation is less than 80-kW. Even though this SRF module suffers from gas condensation, it may still remain free of multipacting because of a low secondary emission due to the limited impact energy of stray electrons accelerated by the RF field in the high power input coupler. In addition, two independent cryo-plants, rated for 460-W at 4.5-K, are dedicated for accelerator operation. One of them is always available to keep the SRF module cold while the other is under maintenance or experiences serious malfunction. Because of this redundant design, the TLS SRF module could be kept cold continuously since its last cooling down in 2009. Thus, the SRF module S1 may have the record for longevity among operational CESR-type SRF modules.

The operation of SRF modules at TPS is more of a challenge. The routine operational maximum forward RF

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power is currently more than 150-kW for each SRF module and will be higher than 200-kW in the near future to sustain an increase in beam current from 300-mA to 400-mA. Enhancement of multipacting due to continuous gas condensation must be controlled by routine conditioning of the high power input couplers. Otherwise, vacuum bursts caused by multipacting cause an increasing trip rate becoming sooner or later unacceptable. In addition, only one cryogenic plant is available for these two SRF modules. Yet, an on-line spare helium screw compressor has been installed to avoid operational interruption during its annual maintenance. For the case of a cold box malfunction a counter strategy must be developed to avoid full thermal cycling.

MITIGATION OF MULTIPACTING ON THE POWER COUPLER

Due to continuous gas condensation on the cold surface of high power input coupler, routine RF conditioning is generally required to desorb condensed gases. Figure 1 records the evolution of vacuum pressure of power coupler while conditioning the #2 SRF module. Similar processing results have been experienced with the #3 SRF module. After RF conditioning, we may believe the power coupler becomes almost free of vacuum activity related to multipacting. Meanwhile, it is not always the case in a real world. A new technique has been developed based on beam processing and is now applied regularly to desorb condensed gases from cold surfaces. This has been demonstrated to be much more effective considering the amount of gas desorbed during processing. Figure 2 demonstrates that a considerable amount of desorbed gases has been pumped out during beam processing which was applied the day following RF conditioning. Conventional RF conditioning is not always efficient to unload the condensed gas and shows therefore a short process memory. More details about beam processing and techniques involved will be discussed elsewhere.

SURVIVAL DURING MAINTENANCE OR MALFUNCTION OF CRYOGENIC PLANT

Very large thermal stresses occur during full thermal cycling potentially causing vacuum leaks, especially during cool down from room temperature to liquid nitrogen temperature. Keeping the SRF module at a temperature below liquid nitrogen temperature can therefore reduce thermal fatigue of indium vacuum seals. On the other hand, keeping the cavities at liquid helium temperature increases the costly consumption rate of liquid helium for days on end in case of a cryogenic plant malfunction. Test runs on a spare SRF module (named S0, from Cornell University) using liquid nitrogen alone have been conducted at NSRRC. The cavity temperature is capable to keep at around 120-K while the insulating vacuum layer is cooled to liquid nitrogen, as shown in Fig. 3. Alternatively, considering the large amount of liquid helium inside the main helium dewar at TPS, being roughly 5000 litres during routine operation, the SRF

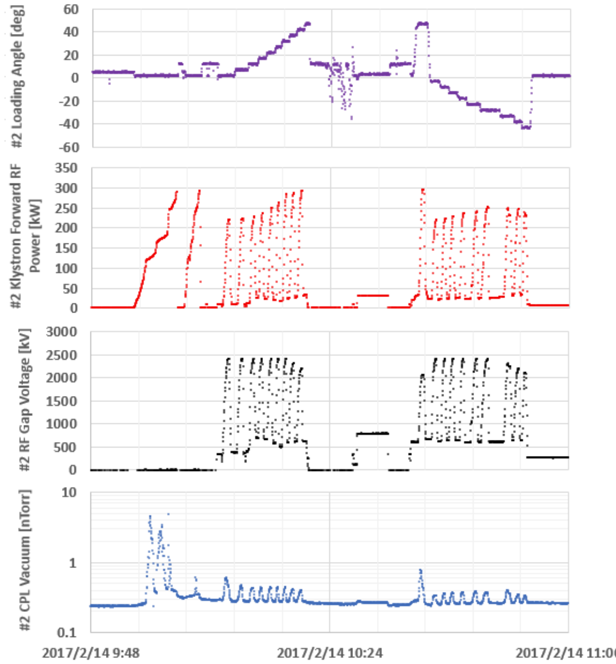

Figure 1: Evolution of vacuum pressure at the high power input coupler of the #2 KEKB SRF module during RF conditioning. The goal of RF conditioning is to reach either a CW RF gap voltage of 2400 kV or a maximum forward CW RF power of 300-kW for various loading angles from 45^{o} to -45^{o}.

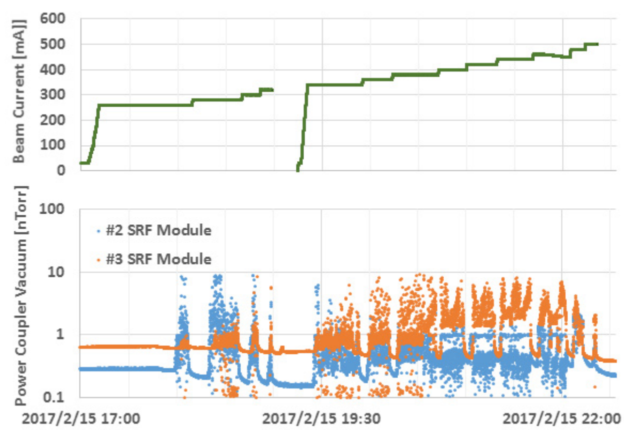

Figure 2: Evolution of vacuum pressures at the high power input couplers of the #2 and #3 KEKB SRF modules during beam processing. The goal for beam processing is to reach a maximum operational beam current of 500-mA.

modules can be maintained at around 30-K for days by taking advantage of cold helium gas in addition to the latent heat. The consumption of liquid helium can be further reduced by maintaining at higher cooling temperatures. An unscheduled problem with the cold turbine occurred while restarting the cold box after rotating the operational helium screw compressor in

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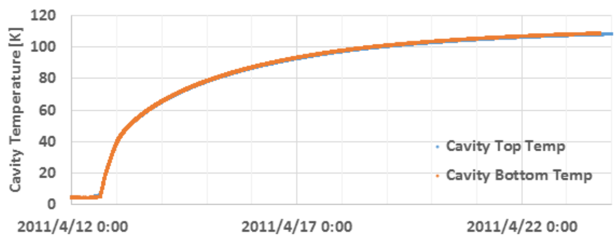

Figure 3: Maintaining the cavity surface temperature at around 120-K after interruption of of the liquid helium supply to the SRF module S0.

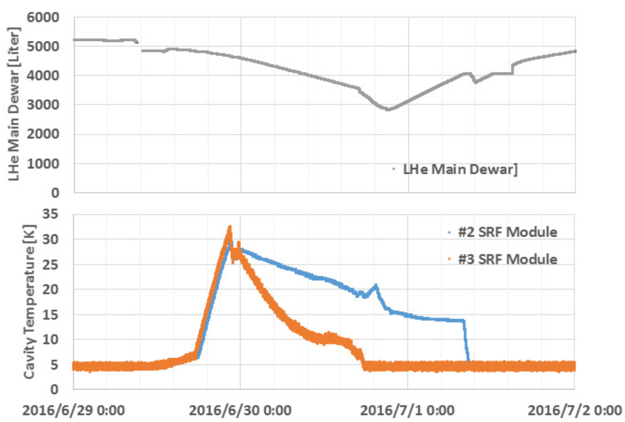

Figure 4: The SRF modules were kept at a temperature below 35-K during the recovery of the cryogenic-plant. Roughly 2000 liter of liquid helium was consumed. Letting the cavity temperature increase to 60-K or even higher would reduce of liquid helium consumption significantly.

summer of 2016. Both operational SRF modules were kept below 30-K for three days while awaiting the recovery of cryogenic operation. The SRF modules could then become available for machine operation in only a few hours after successful recovery of the cryogenic operation. The evolution of operational temperature during this incident is plotted in Fig. 4. Note that some liquid helium was consumed to keep the transfer lines at liquid helium temperature. Later, routine SRF operation demonstrated that our treatment was not harmful to the SRF performance while avoiding a full thermal cycling.

RESULTS OF SRF OPERATION AT NSRRC

Figure 5 and Figure 6 summarize the operational status of complete storage ring RF systems with SRF modules at TLS and TPS, respectively. The SRF module at TLS has been kept cold during the past 7 years since 2009. Roughly two scheduled beam processing operations are scheduled per year. The SRF modules for the TPS were installed in summer 2015 and reached their design maximum beam current of 500-mA at the end of 2015. The routine operational beam current is 300-mA in top up mode. Long term reliability test runs at 400-mA in top-up

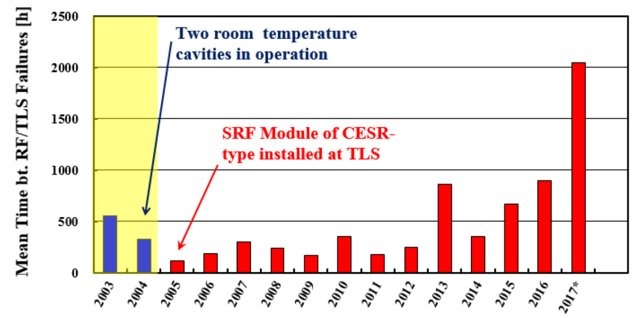

Figure 5: Operational statistics for the storage ring SRF module at the Taiwan Light Source, TLS. The RF operational statistics in 2017 is counted from January to March only.

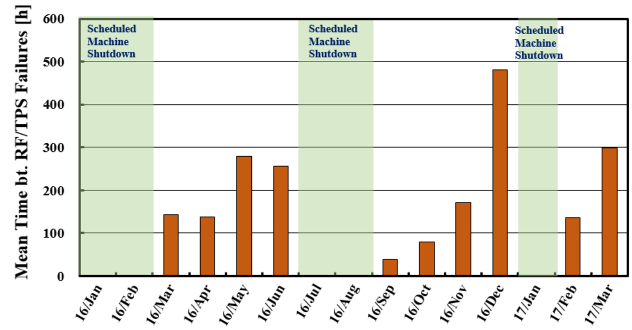

Figure 6: Operation statistics for the storage ring SRF modules at the Taiwan Photon Source, TPS.

mode have been performed successfully during a total of more than 90 hours in early 2017. Its first and last full thermal cycling after SRF operation at TPS was done early in 2016 as part of the license application to officially operate a cryogenic plant. Since then, the TPS SRF modules are kept cold. The cavity vacuum pressure is kept stable thanks to regular beam processing to unload condensed gas. Full or partial thermal cycling for any of the operational SRF modules at NSRRC is not foreseen during 2017. We have confidence in our successful SRF operation both for the TLS and the TPS. Meanwhile, increasing the operational beam current to 400-mA or even higher at the TPS will bring new challenges.

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