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AUTOMATION OF SUPERCONDUCTING CAVITY AND SUPERCONDUCTING MAGNET OPERATION FOR FRIB*

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Abstract

The superconducting (SC) driver linac for the Facility for Rare Isotope Beams (FRIB) is a heavy ion accelerator that accelerates ions to 200 MeV per nucleon. The linac has 46 cryomodules that contain 324 SC cavities and 69 SC solenoid packages. For linac operation with high availability and high reliability, automation is essential for such tasks as fast device turn-on/off, fast recovery from trips, and real-time monitoring of operational performance. We have implemented several automation algorithms, including one-button turn-on/off of SC cavities and SC magnets; automated degaussing of SC solenoids; mitigation of field emission-induced multipacting during recovery from cavity trips; and real-time monitoring of the cavity field level calibration. The design, development, and operating experience with automation will be presented.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) driver linac is designed to accelerate ion beams, from hydrogen to uranium, to 200 MeV/u. It has a folded layout as shown in Fig. 1, which consists of three linac segments (LS1, LS2 and LS3) connected with two folding segments (FS1 and FS2), and a beam delivery system to deliver the accelerated beam to target. Linac segments and folding segments have 46 cryomodules with 324 superconducting (SC) cavities for accelerating, 69 SC solenoid packages for transverse focusing and steering. Four SC dipoles has been installed in FS2 to steer and deliver beam from LS2 to LS3 [1]. To operate large scale SC devices with high availability, the implementation of automation tools is necessary and important.

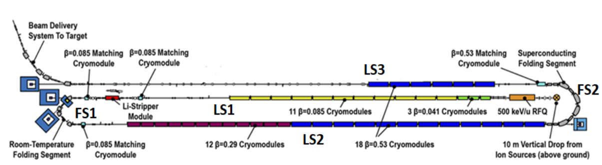

Figure 1: Schematic layout for FRIB driver linac.

AUTOMATION FOR SC CAVITY

Cavity Auto Turn-on

The FRIB cryomodules contain 104 quarter-wave resonators (QWR) and 220 half-wave resonators (HWR) for beam accelerating. Manually turn-on each cavity is time consuming and not suitable for the user operation. Since all cavity had been commissioned, the automatic turn-on program has been developed based on experts' commissioning experience. Two auto turn-on programs for QWR and HWR single cavity are developed [2]. After commissioning test succeed, they are duplicated for all QWRs and HWRs and running at Experimental Physics and Industrial Control System (EPICS) Input/output controller (IOC) level. With cavity control parameters be optimized, the cavity can be turned on in 1 minute [2]. The auto turn-on program is also improved, in each cavity commissioning or maintenance time period, new logic update will be tested to enhance the performance and reliability. Figure 2 shows the QWR and HWR auto turn-on logic sequence. Currently there are two new steps for performance improvement, which will be tested during the next linac maintenance time period.

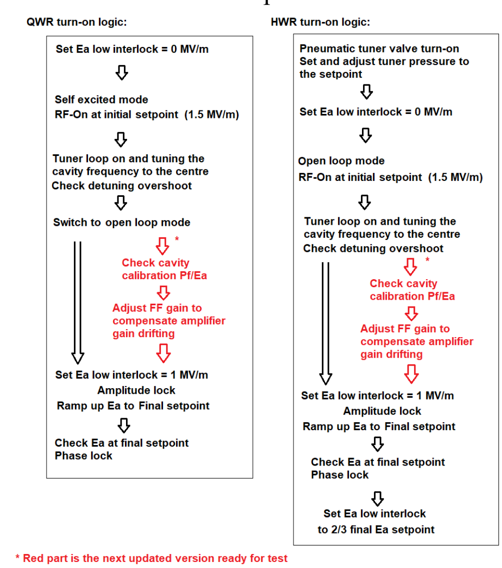

Figure 2: FRIB QWR and HWR auto turn-on logic. Black part: current logic, red part: new logic for next update.

Reliable single cavity level auto turn-on program can be integrated to the group one button turn on. So far, for the LS1 and FS1 104 QWR cavities, a simple CS-Studio OPI control page has been made (Fig. 3, left) for operators to use. Operators are able to turn-on all QWRs within 2 minutes with "one button". For 220 HWRs, currently the auto turn-on is performed by SC cavity experts, all cavities can be group turn-on through a Python script (Fig. 3, right). Similar OPI will be developed in the future after HWR single cavity level auto turn-on program being improved further.

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Figure 3: QWRs and HWRs group turn-on. Left: CS-Studio OPI for QWRs. Right: Python script for HWRs group turn-on.

Pneumatic Tuner Valve Calibration

The FRIB HWR use a pneumatic tuner [3], which is linked to the HWR beam port cups and actuated by bellows. The bellows can be expanded or contracted by helium gas pressurization or discharge. The bellows connected with a tuner gas pipe has two solenoid valves, one connected to the gas supply pipe, the other connected to the gas return. The LLRF system controls these valves by setting the voltages via a frequency feedback loop. For precise tuning control, the solenoid valves must to be calibrated: measuring the gas flow rate versus valve control voltage. The calibration of the valves is critical to HWR cavity automatic turn-on and also impacts pneumatic tuner operation performance. The regular calibration check is needed for all valves in machine maintenance time period. Manual calibration for one valve will take 3 minutes and it requires CS-Studio control and plots page prepared and operated by SC cavity experts. For 220 HWRs, which have 440 valves, the manual calibration on all valves is very time consuming. The automatic calibration tool (see Fig. 4) significantly reduces this time cost. With the auto calibration implemented, all 440 valves calibration can be proceeded within two hours.

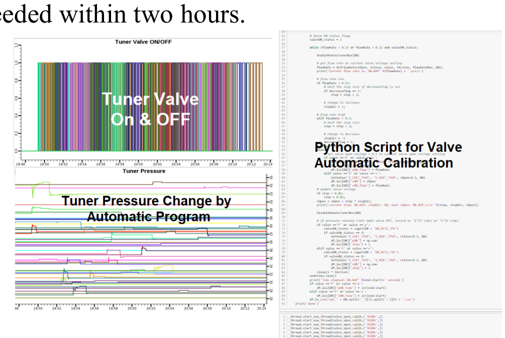

Figure 4: Automatic calibration program for pneumatic tuner valves. Left: valves calibration in one cryomodule sequentially, do all cryomodules in parallel done within 2 hours. Right: the auto program is developed by Python Script.

Cavity Field Reduce and Recover

The cavity field reduce and recover automatic program is to fast recover tripped QWR cavity in the LS1. The FRIB QWR has multipacting low barrier, since the cavity commissioning time is relatively limited, conditioning QWRs multipacting low barrier had been replaced with RF turn-on jump through. The QWR is turned on with initial 1.0 MV/m field set-point to jump through the low barrier (β = 0.085 80.5 MHz QWRs, the low-field multipacting appears at Eacc of ~10 kV/m) [4]. However, if a cavity is off but adjacent cavities are on and have field emission (FE) electrons, which will result in higher chance for the "off" cavity to excite strong low barrier multipacting at the beginning of the auto turn-on. Then the auto turn-on jump through step will fail and the cavity will get stuck in the low barrier for a long time. So if any cavity, which has high FE cavities nearby, tripped off during the operation, recover this cavity from trip will have higher chance of failure.

To solve this issue, we reduce the high FE cavity field to 1.5 MV/m (no FE at this low field), then turn tripped cavity back on to jump through the low barrier. Once the cavity back to the set-point, recover the field level for that high FE cavity. To reliable perform the high FE cavity field reduce and recover, an automatic program has been implemented. Operators are able to go through reduce and recover procedures with minimal training to fast recover cavity from trips. Figure 5 shows the program logic and CS-Studio OPI, so far the logic is running at workstation client level as the initial version. In the future, it will be moved into EPICS IOC level.

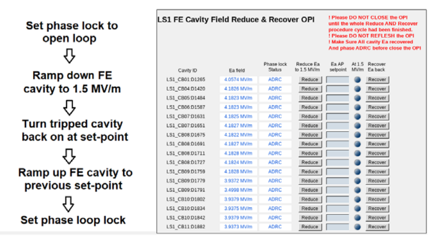

Figure 5: Cavity field reduce and recover automatic program. Left: auto program logic. Right: CS-Studio OPI operation page.

AUTOMATION FOR SC MAGNET

The FRIB 46 cryomodules contain 69 SC solenoid packages, and each SC solenoid package has one solenoid and two correction dipoles. In the FRIB tunnel FS2, there are 4 SC dipoles have been installed. For all these SC magnet power supplies fast turn-on and stability check is required. To perform the turn-on and status check with high availability, automatic programs have been implemented. The first version of the program was on the client workstation level using Python script [5]. Right now it has been upgraded with State Notation Language and is running at the EPICS IOC level, so the performance and reliability of the automatic program has been enhanced.

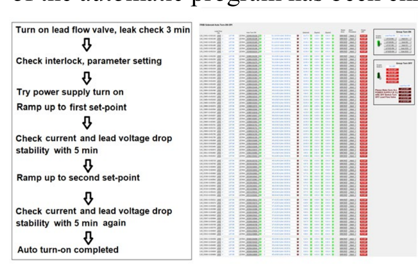

Figure 6: Left: SC magnet auto turn-on and status check program logic. Right: CS-Studio OPI page for cryomodule solenoid packages.

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Figure 6 shows the auto turn-on and status check logic sequence and the CS-Studio OPI user interface. One button group turn-on/off for all SC magnets in different linac segments is also implemented. Operators are able to turn on all SC-magnet in different segments and done with stability checks within half hours.

The automation for SC magnet development is ongoing, more SC magnets in beam delivery system, which is right after FRIB driver linac, require transition to operations with high availability. These SC magnets auto turn-on and operation related tools are under development. Figure 7 shows current operation programs for FRIB SC magnets. A user interface page with subpages for cryomodule solenoid packages turn-on, degaussing, FS2 dipoles turn-on, target hall SC magnets turn-on, auto turn-off is developed. All automation logic is running at the EPICS IOC level. The updates and improvements for the auto turn-on logic are also required. With long term operation experience, new steps will be added into the program. In the next maintenance period new logic for magnet current stability check will be tested, which will solve the current read back and set-point offset mismatch issue. The current set-points saving and re-load will also be tested and implemented. It records power supply settings in the previous operation, and can re-load settings from the record for the next operation.

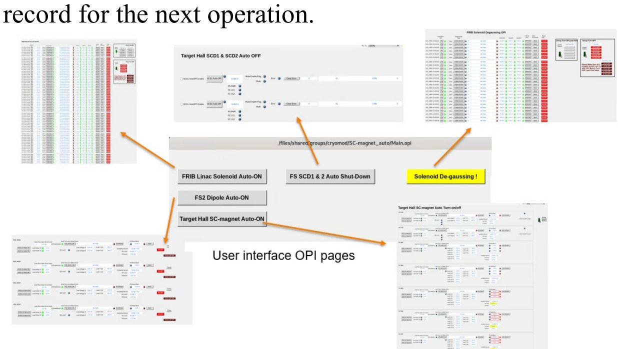

Figure 7: Automation tools user interface for SC magnets.

MONITORING AND TRACKING TOOL DEVELOPMENT

Cavity Field Calibration Monitor

Cavity field calibration consistency is important for the high reliability operation. Monitoring the cavity field calibration online will give operator alarm in real time during the beam run. Figure 8 shows a calibration monitor tool, it watches the ratio between forward power and accelerating gradient for each cavity, then compares it with expected value and send an alarm if a mismatch is detected. The current program is a test version running at the client workstation level. Future plan will be implemented to the EPICS IOC level.

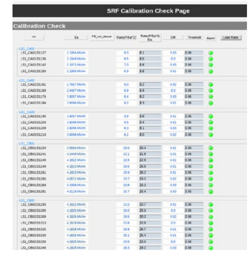

Figure 8: Cavity field calibration monitor.

Automatic Parameter Checking and Tracking

For SC cavity and magnet operation parameters reliable management and device maintenance, an automation tool is planned and under developing. The tool will catch the device control parameter setting changes, save the change data automatically. If the parameter new change is not suitable for current operation, people can re-load previous setting. Figure 9 shows the schematic of the automation tools for parameter setting changes.

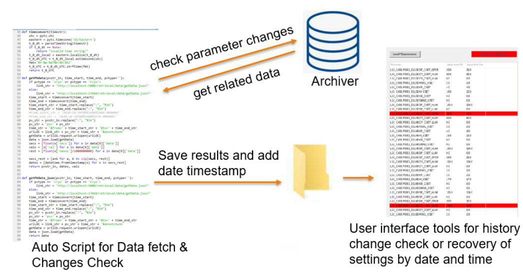

Figure 9: The design schematic for SC device parameter checking and tracking tools development.

SUMMARY

Automation tools for large scale FRIB SC cavity and SC magnet operation is necessary and important. The implementation of automatic turn-on, recovery, monitoring and tracking tools increases the machine stability and reliability. Future automation tool development will focus on high-availability user operation, increasing the available machine time, and supporting beam power ramp-up.

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