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Solenoid Automatic Turn-On and Degaussing for FRIB Cryomodules*

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Abstract

The superconducting driver linac for the Facility for Rare Isotope Beams (FRIB) will accelerate heavy ions to 200 MeV per nucleon. The linac includes 46 SRF cryomodules, with a total of 69 solenoid packages for beam focusing and steering. For efficient beam commissioning and future operation, all of the solenoids must be turned on and reach a stable operating condition in a short time. Additionally, when a warm-up of the cryomodules is needed, degaussing of the solenoid packages is needed to minimize the residual magnetic field in the SRF cavities. An automatic turn-on and degaussing program had been implemented for FRIB cryomodules to meet these requirements. This paper will describe the design, development, and implementation of the automated solenoid control program.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) driver linac has 69 solenoid packages be installed. There are 6 length=250 mm solenoid packages are installed in three 0.041 cryomodules; 63 length=500 mm solenoid packages are installed in eleven 0.085 cryomodules, twelve 0.29 cryomodules and eighteen 0.53 cryomodules. Table 1 shows parameters of these solenoid packages [1].

Table 1: FRIB Cryomodule Solenoid Package Parameter

	Aperture	Solenoid integrated square strength	Length	Maximum magnetic field	Steering magnetic field	Steering integrated field strength	Solenoid Current	Steering Current
0.041 Cryomodule	40 mm	13.6 T²m	250 mm	8 T	0.12 T	> 0.03 Tm	90 A	19 A
0.085, 0.29 and 0.53 Cryomodule	40 mm	28.2 T²m	500 mm	8 T	0.12 T	> 0.06 Tm	90 A	19 A

When the solenoid package is turned-on and ramp-up to a high current level, the lead can temperature and lead voltages of the solenoid and steering dipoles will go up. The lead voltage has a high limit interlock set-point which can interlock the power supply. To keep the lead voltage not reached the limit, there is a flow cold helium gas out from the cryomodule 4 K header that can cool-down the lead and make the lead can temperature drop then the lead voltages will drop too. The cooling gas flow rate can be controlled by the lead flow valve opening degree. Once all lead voltages drop to a reasonable range, the lead flow valve control will keep the lead temperature not drop too much that can avoid the lead get frozen. Since all lead valve PID control parameters are already optimized during the solenoid commissioning, they don't need to be adjusted every time. Just if there is any instability happen, PID parameters will be adjusted again and some relevant changes will be investigated further. So to make sure the lead valve control is still good, the stability check in a short time for lead can temperature and lead voltages is important during the solenoid turn-on. For efficient beam commissioning and future operation, fast turn-on all 69 solenoids and automatic stability check is necessary.

Before the cryomodule warm-up, degaussing of the solenoid packages is needed to minimize the residual magnetic field in the SRF cavities [2]. The degaussing procedure requires the solenoid and steering dipoles ramp-up to maximum current first, then next each cycle ramp-down by 25% with opposite current polarity until the current go down to zero [2]. The solenoid maximum current is 90 A, with each degaussing cycle current decreased, there are at least 20 cycle times to ramp-done the current below 0.5 A. To implement the degaussing procedure, an automatic ramping check and setting is required.

To achieve these necessary requirements, an automatic program had been developed. Fast turn-on all solenoid packages and automated degaussing ramping control had been implemented on all solenoid packages of FRIB linac.

AUTOMATIC CONTROL STATE MACHINE

The solenoid package automatic control program is include two part: 1) auto turn-on, 2) degaussing. The structure for both parts are similar, main control logic is based on a state machine with 5 state: idle waiting, power supply turn-on, load set-point, ramp to set-point/status check and error. Figure 1 shows state-chart for these two parts logic.

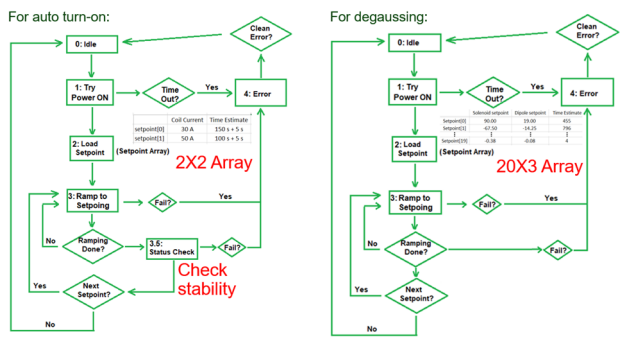

Figure 1: Solenoid auto turn-on and degaussing state-chart.

Left state-chart is auto turn-on procedure state machine. State "0" idle will do nothing but waiting for start. State change from "0" to "1" will try turn on the power supply of the solenoid package. Then go to state "2" that will load current set-point array. For auto turn-on, there are only two current set-points: 30 A and 50 A. State go "3" that will ramp solenoid current until it gets the set-point. State "3.5"

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will check stability that include set-point current read back confirm, lead can temperature and lead voltages stability check. If solenoid status is stable, state will jump back to "3" to load next set-point or go back to initial state "0: Idle" to finish the procedure, otherwise state machine will go state "4: Error". Any interlock happens will also trig the state machine jump into state "4" (This jump doesn't show in the Fig. 1 chart). The state "4: Error" can be reset and jump back to state "0" if all interlocks are cleaned.

Right state-chart is degaussing procedure state machine, it is similar with "auto turn-on". Difference is the degaussing procedure have 20 set-points current for solenoid and another 20 set-points for steering dipoles, the simulated plot for degaussing procedure with these 20 set-points is shown in Fig. 2. The time cost will be about 1 hour for one solenoid package based on the coil ramp rate. There is no stability checking needed for degaussing, so the state "3.5" was removed in degaussing logic.

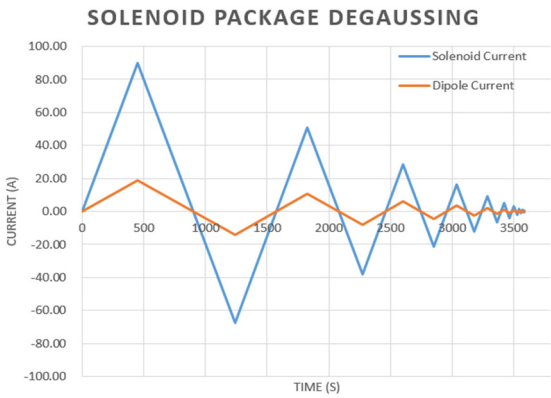

Figure 2: The simulated plot for the solenoid package degaussing procedure with 20 set-point current setting.

CLIENT LEVEL PROGRAM IMPLEMENTATION

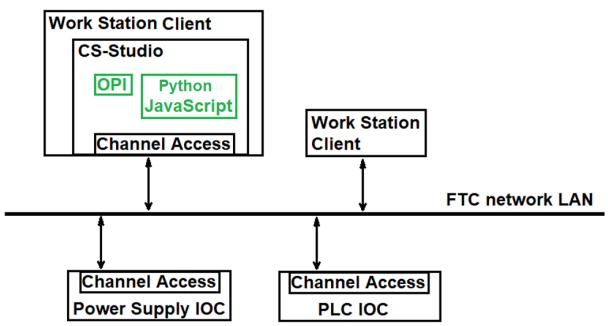

Figure 3: The client level program implement schematic.

To implement the automated procedure, a client level program had been developed. Figure 3 shows the implement schematic. The program is based on the CS-Studio [3] OPI which embedded Python and JavaScript code for the auto control state machine. The OPI program is run at a client machine which is usually a work station. The work station can control power supply of the solenoid package through the "FTC network" (the "FTC network" is a control network based on EPICS and it is for FRIB control only).

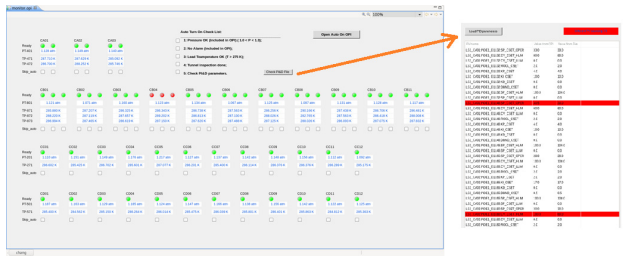

Figure 4: The CS-Studio OPI program: interlock status check page and lead flow valve PID parameters check page.

The CS-Studio OPI program is comprised of the following three pages: 1) interlock status check, 2) solenoid lead flow valve PID control parameters check, and 3) auto turn-on or degaussing page. Figure 4 shows first and second pages. On "interlock status check" page, PVs of all solenoid packages include PLC interlock latches, 4 K header pressure, lead can temperature are shown. Operator can follow the check-list on the page to check the status before energize solenoid packages. For PID control parameters of lead flow valves check (the last line of the check-list). There is a button can open the "lead flow valve PID parameters check" page, which can help people to compare the difference between current parameters with history record (usually is a local text file that saved last time commissioning parameters) to make sure all parameters are traceable. Once the check-list is checked, the third page "auto turn-on/degaussing" can be open (the Fig. 5).

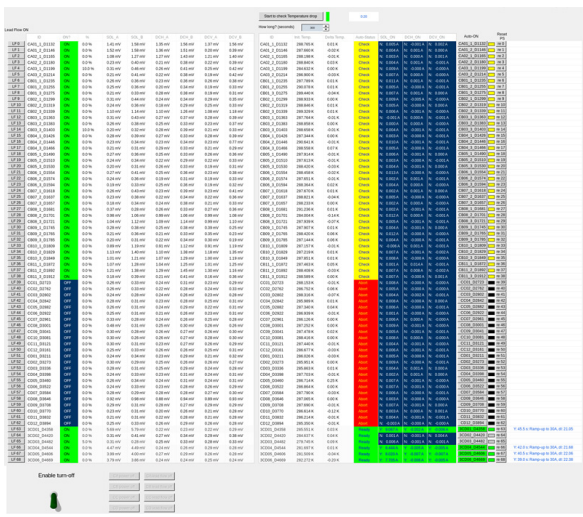

Figure 5: The CS-Studio OPI program: auto turn-on or degaussing page.

On that page, the lead flow valve of the solenoid package can be turned on. After the lead flow valve on, the lead can temperature drop can be checked automatically to confirm the valve is not leaking. Then the auto turn-on or

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degaussing procedure will be permitted to start. All lead voltages, lead can temperature and power supply read back for solenoids and steering dipoles are shown in the page with different colour to notice current status.

COMMISSIONING

The auto turn-on program had been operated every time for the beam commissioning in recently. Each time the solenoid package turn-on is about one hour earlier before the beam commissioning start. The Fig. 6 shows the detail information about the auto turn-on for all 69 solenoid packages in the FRIB tunnel. All solenoids are able to be automatic turn-on and stability check within half hours.

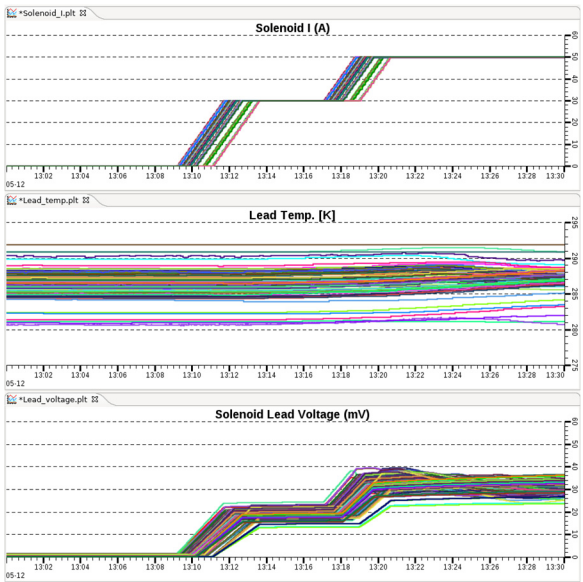

Figure 6: All 69 solenoid packages auto turn-on details in FRIB tunnel.

The automatic degaussing program had been operated in May 2020 due to the FRIB linac cryomodules warm-up requirement. With the automated control, all solenoid packages are able to be degaussed efficiently. The Fig. 7 shows the solenoid degaussing current ramp down by the automatic program detail information.

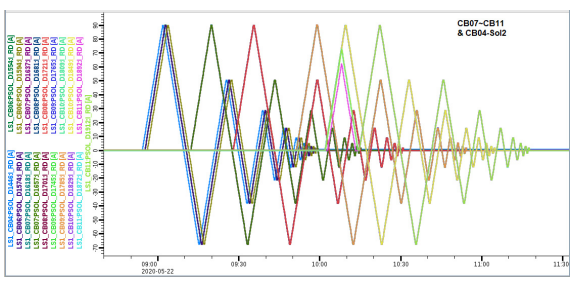

Figure 7: Solenoids automatic degaussing.

IOC LEVEL PROGRAM DEVELOPMENT

So far, the client level automatic program worked fine for the beam commissioning and the degaussing requirement. The logical for the solenoid package auto turn-on and automatic degaussing had been verified. But for the future reliable operation, this program is needed to run at an EPICS IOC [4]. Once the program is upgraded to an IOC level, the auto control will run at a more reliable operating system(OS) which is much stable and quick than the client OS. And also, all clients can operate it through EPICS channel access without occupy additional resource from local client. Any client is able to run the program and observe the program running status at any time without conflict due to two or more clients operating it at the same time. The Fig. 8 shows the schematic of the IOC level program.

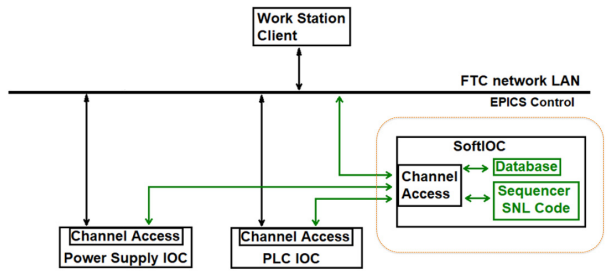

Figure 8: The IOC level program implement schematic.

Since the IOC level program has the same logical procedure as the client level one, the main developing work is to convert the client level Python and JavaScript code to State Notation Language (SNL) [5] for the EPICS IOC running. After the code conversion work done, the IOC level program was tested on a simulator with simulated PVs (such as cryomodule 4 K head pressure, lead can temperature, PLC interlock and power supply current setting etc.), the detail schematic is shown in Fig. 9. In the "solenoid auto IOC", some new PVs also be created for SNL code running use. Right now, all test and verification works are down, the program is ready to deploy to the FTC network.

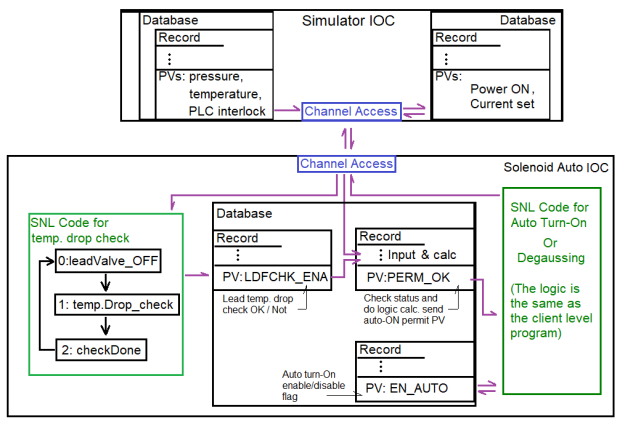

Figure 9: The IOC level program test with simulator IOC

SUMMARY

The automatic solenoid package control program had been developed, tested and operated at the client level. The following step IOC level program development and verification with the simulator had been done. Next step

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will be the IOC level program deployment, test and operation on FTC network for FRIB solenoid packages.

REFERENCES

[1] M. Xu et al., "FRIB LS1 Cryomodule's Solenoid Commissioning", in Proc. 19th Int. Conf. RF Superconductivity (SRF'19), Dresden, Germany, Jun.-Jul. 2019, pp.671-674. doi:10.18429/JACoW-SRF2019-TUP089

[2] K. Saito et al., "FRIB Solenoid Package in Cryomodule and Local Magnetic Shield", in Proc. 19th Int. Conf. RF Superconductivity (SRF'19), Dresden, Germany, Jun.-Jul. 2019, pp. 235-240. doi:10.18429/JACoW-SRF2019-MOP072

[3] CS-Studio, https://controlsystemstudio.org

[4] EPICS Input / Output Controller (IOC) Application Developer's Guide https://epics.anl.gov/EpicsDocumentation/AppDevManuals/AppDevGuide/3.12BookFiles/AppDevGuide.book.html

[5] State Notation Language and Sequencer, https://www-csr.bessy.de/control/SoftDist/sequencer/