High Field Test of sPHENIX Superconducting Magnet

Kin Yip (C-AD)

1 Introduction

After a successful Low Field Test in March 2016 [1], we started to build a Return Flux Steel box enclosing the Superconducting Magnet Coil in Bldg. 912, under the leadership of Jon Hock, David Phillips and Jim Mills, for this High-Field Test. It has taken a long time mainly because the technicians, riggers, carpenters and other necessary resources are not easy to come by when we need them. The Return Flux Steel was completed when the last section of the steel wall (on the Non-Lead End) was installed on Dec. 14, 2017.

Ray Ceruti's team and Sonny Dimaiuta's team (such as Joe D'Ambra) from the Superconducting Magnet Division have helped us with installing the Extension and junction boxes as well connecting them the superconducting splices.

Paul Orfin, Roberto Than, Tom Tallerico, Brian Van Kuik and other Cryo group members (such as Richard Meier) have continued to help us with the cryogenic system for this Test.

The biggest change in personnel between the above-mentioned Low Field Test and this High-Field Test is in the electrical engineers, namely Pablo Rosas responsible for the Power Supply and Carl Schultheiss, Zeynep Altinbas and Charles Theisen for the Quench Protection System.

Figure 1 shows the block diagram of the power supply and quench protection system for the Test.

Figure 2 shows the locations and original designations of the voltage taps and 4 temperature sensors (TT1786, TT1787, TT1788 & TT1789) that we have added before this Test.

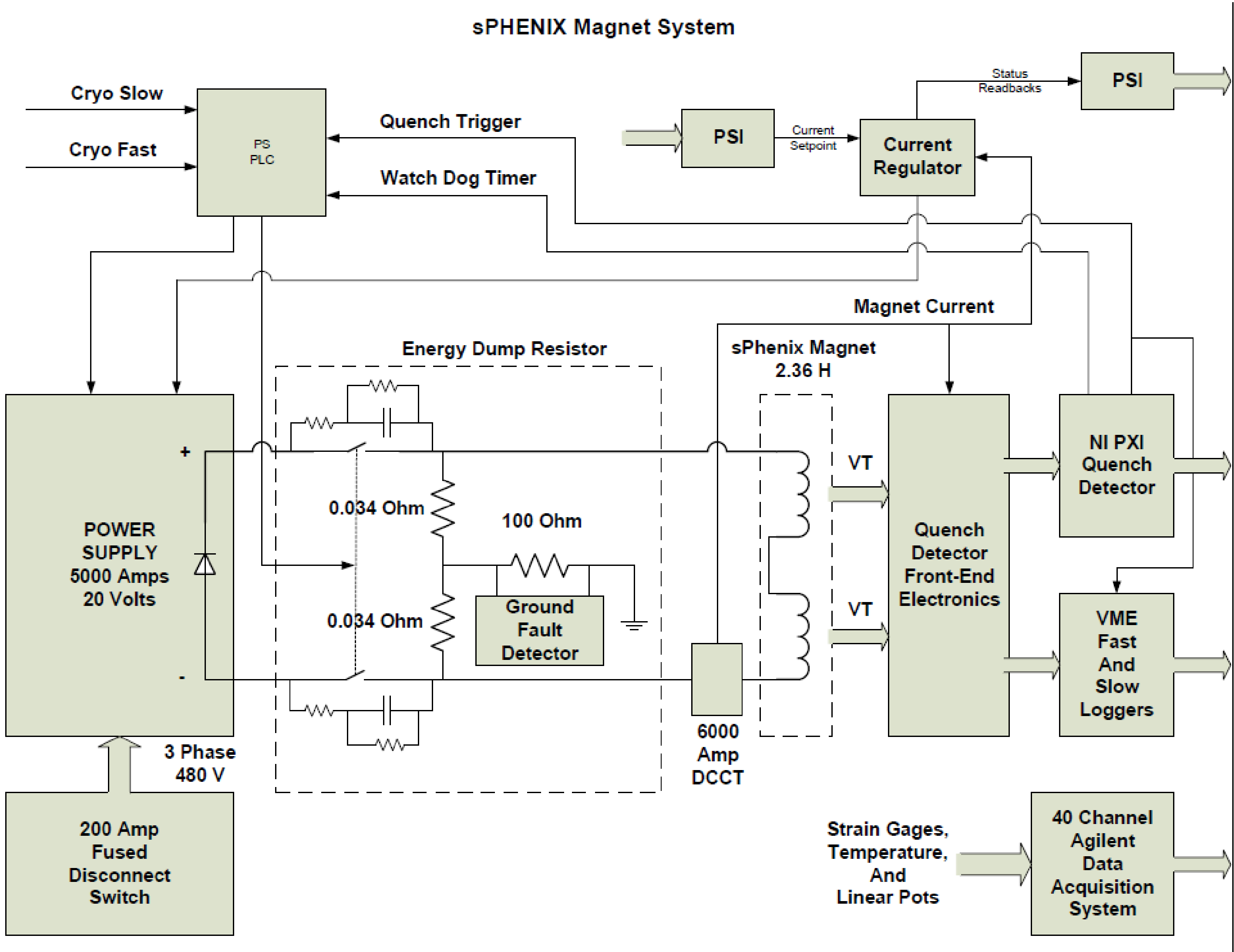


Figure 1: Block Diagram of the Power Supply and Quench Protection System (drawn by Carl Schultheiss).

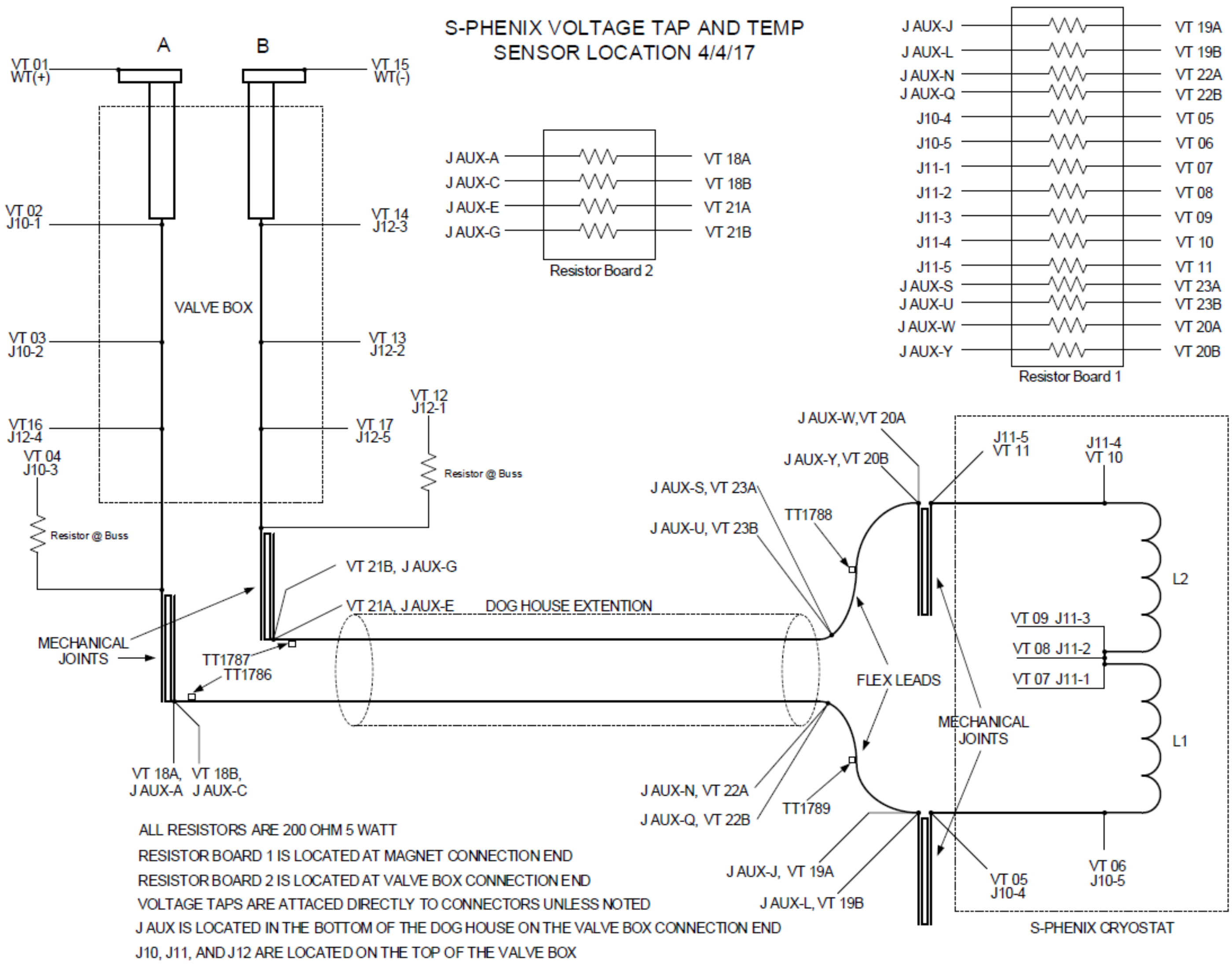


Figure 2: The designation and locations of the voltage taps and 4 temperature sensors that we added for this Test (drawn by Sonny Dimaiuta).

When the Cryo Extension (the piece between the new junction box under the Valvebox and the old junction box attached to the Magnet Cryostat) was made in the Superconducting Magnet Division in the basement of 902, we have marked X’s on the superconducting busses (A and B) to indicate where the new RTD (resistive temperature detector) should be mounted. The pictures of the RTD TT1786/TT1787 are shown in Figure 3, Pic 1 and Pic 2 respectively. The example of markings, X’s, can be seen in Figure 3, Pic 3. For each bus bar A and B, the RTD was placed on top of the Kapton insulation tap of the power bus lead with a small film of Apiezon grease between the Kapton tape and the RTD. After that, the RTD and the board that the RTD is mounted to, were wrapped 4 times with ½” glass cloth tape with some pressure applied and then tied off in three spots with Kevlar lacing cord for a firm tight fit. At the end, a film of “Devcon 5-Minute Epoxy” was placed on the glass tape and knots to make it secure as shown in Figure 3, Pic 4.

Pic 1

1786
LakeShore
folded
Model Number: XCX-1050-CY-4L-146
Serial No.s:
A/X40383
B/X40384
TT 1786
691

Pic 2

1787
LakeShore
folded
Model Number: XCX-1050-CY-1.4L-241
Serial No.s:
A/X40388
B/X40389
TT 1787
692

Figure 3: Pictures of the RTD (resistive temperature detectors), "Pic 1" and "Pic 2" and their intended locations on the Cryo Extension, "Pic 3" and "Pic 4".

2 Time

After some troubleshooting on Thursday (Dec. 14), the cool-down of the Superconducting Magnet really started on Dec. 15, 2017 after the Cryo group decided to implement a temporary solution such that the valve “3613” was only 50% shut (not fully shut). [Later, it was found that the it was not electrical noise that shutting down the valve but it was due to a software counting bug that cause the valve to be shut.] The cool-down then really started Friday morning.]

The first short-circuit tests with a copper bar installed between the Current Leads (A and B) with a plastic cover was performed on Dec. 20 and 21, 2017 by Pablo Rosas and his technicians including Lionel Desulme, Chris Zarcone, et. al.

3 Results

In the afternoon of Feb. 13, 2018, we reached ~4830 A and due to the availability of Liquid He, we stayed for about 40 minutes. They actually watched that the gas-cooled lead voltage stabilized (ie. not going up any more) before they started the slow discharge. Carl and the Cryo group have been discussing about optimizing the lead flow rate from 0.27 g/s to 0.33 g/s as the max. (at 5000 A). Brian van Kuik told me that the max. they reached was about 0.31 g/s.

This morning, when we tried to ramp at 2 A/s to 4000 A, the pet page etc. suddenly all disappeared in front of us (in 912 or my office or anywhere). The C-AD control file system crashed ! (When did this happen last time ?!) One felt like everything was against us, at that point. At that time, the power supply/magnet was ramping up and after the file system crash, we could only observe from Zeynep's quench-detection system (PXIe) screen or Pablo's power supply touch-screen. Around 2500 A, Carl's phase-locked-loop (PLL) was lost which caused Zeynep's PXIe to issue a fast-discharge (for quench protection) — which had not happened since we started testing in 912. Maybe, the loss of PLL was due to the control system failure or maybe not ??! We couldn't ramp — even John Morris discouraged from there doing so — as there was no logging (slow logging or fast logging) to monitor etc.

Luckily, shortly before 1 pm, the control system was back to operation. After testing a bit at 100 A, we started ramping at 2 A/s to 4000 A and then 2 A/s in 200 A step (or 230 A for the last step).

As mentioned, we reached ~4830 A and stayed there for ~40 minutes and did the slow-discharge, to avoid the Liquid Helium tank being empty. The slow-discharge is slow and the calculator that I created said that it'd take ~6102 seconds to go from 4830 A to 0. It's slower at the end :-) Just like BaBar, people don't want to wait for it to slowly go to 0. So, at below 1000 A (or ~966 A or so), we did a fast discharge. This saved waiting for another almost 40 minutes. Figure 3 shows the entire ramping and discharge.

I attached the 2018-2-13.gif for today's current and Magnetic field. Our Opera calculation/simulation assuming

1010 steel, for this Return Flux (Steel Box), predicts a magnetic field of 1.37 T at 4596 A. At ~4830 A, we got ~1.34 T whereas at 4600 A, we got ~1.275 T. Almost 7% lower than expectation. I guess the probe was probably not exactly at the center and the 40+ years old steel is far from what we expected (rusty too).

Today, a surveyor was also there trying to measure any sidewards expansion and I heard that he got only 0.002 inch (within their error/uncertainty) between 0 and 4000 A. Jon Hock came to my office to make me plot his linear pots and there we also saw the maximum of 0.002 inches between 0 and 4830 A. These are all smaller than what the engineers have been worried about.

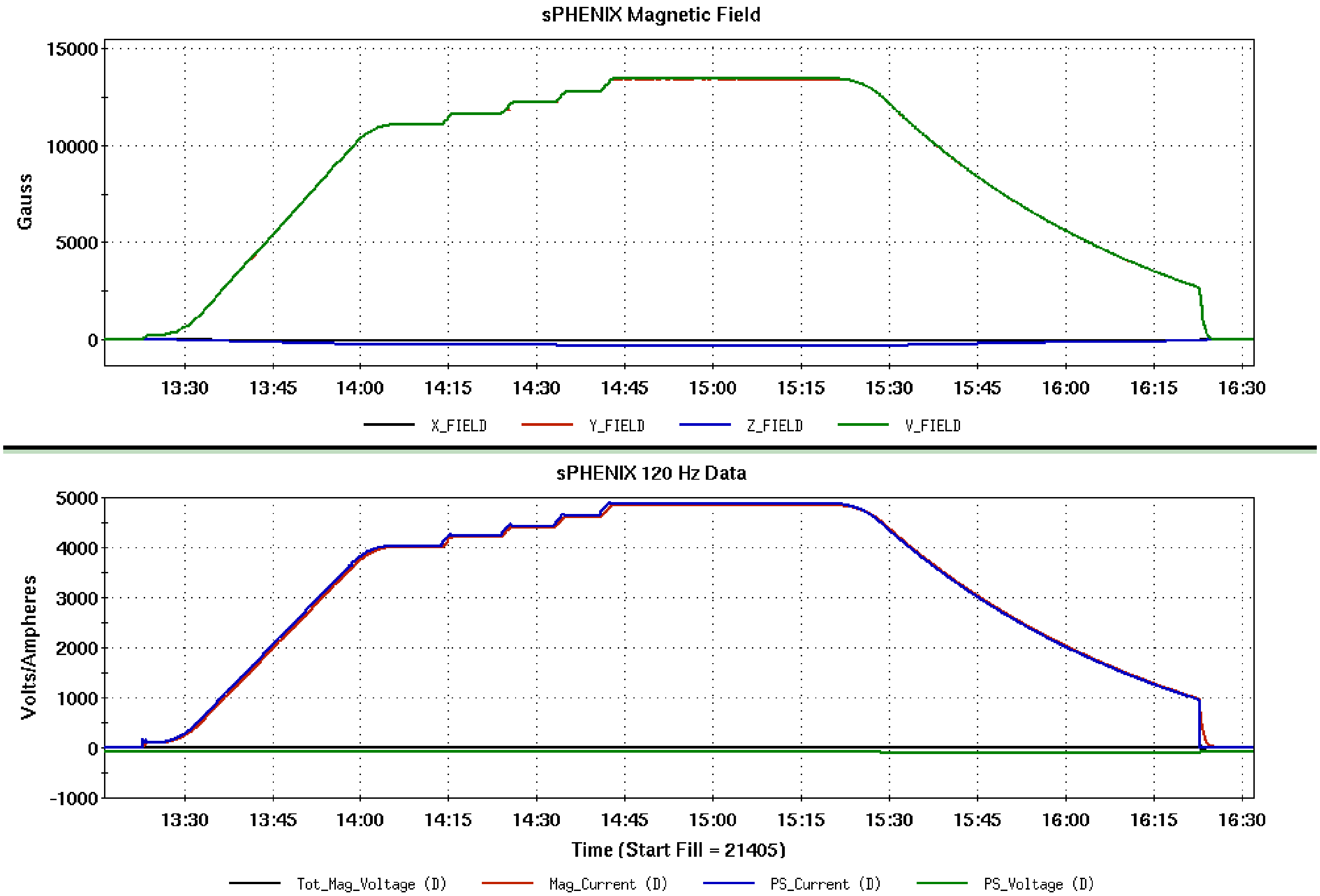


Figure 4: The ramp to 4830 A on Feb. 13, 2018, with the Magnetic Field at the top and the Current at the bottom.

After a few days for the Plant to regenerate liquid He, in the morning of Feb. 16, we tried to ramp up at 2.5A/s at 1000A step. When the current more or less reached 3000 A, the Magnet seemed to quench (due to inner/outer difference blowing up).

Zeynep and Carl both thought that it's real. An hour later, after the cryo recovered, we tried to ramp up at 2A/s. From 4000 A, when trying to ramp to 4830 A without stopping at 200 A step (like last Friday), we quenched at 4410 A. This is the worst fast discharge and helium jumped out at the top.

2 hours later, we tried again and since nobody wanted to see quenching again, this time, we ramped at 2A/s to 1000A, 2000 A and then at 1.5 A/s to 3000 A, 4000 A and then at 200 A step, like last Friday, but at 1.5 A/s to 4830 A. We stayed there for 36 minutes (from the LogView) until the Paul Orfin said that we had only liquid helium left for slow discharge.

We have gone up to 4830 today again. It looks like that we couldn't and can't really try to ramp too fast.
[We kind of followed the Run Plan for those 2.5 A trials.]

Wes Craddock told me (today):

" As for magnet ramp rate the number I remember (not totally certain, but is clearly in the log books) is 1.5 A/sec = 50 min to 4600 amp. However, this was only after we had become very comfortable with the magnet. If I were in your shoes, I would pick a more conservative 90 minutes and then watch temperatures as I shortened the ramp time. "

So, he's kind of suggesting we should play safe at least at the beginning of experimental operation at ~1 A/s. I shared the feeling with Carl that if we just dwell a bit at each step before going up and we probably will be OK.

Since we witnessed the fast discharge at ~4410 A, we don't really need to do the fast discharge at 4830 A. And we prove that we can ramp the magnet again even after such a violent fast discharge.

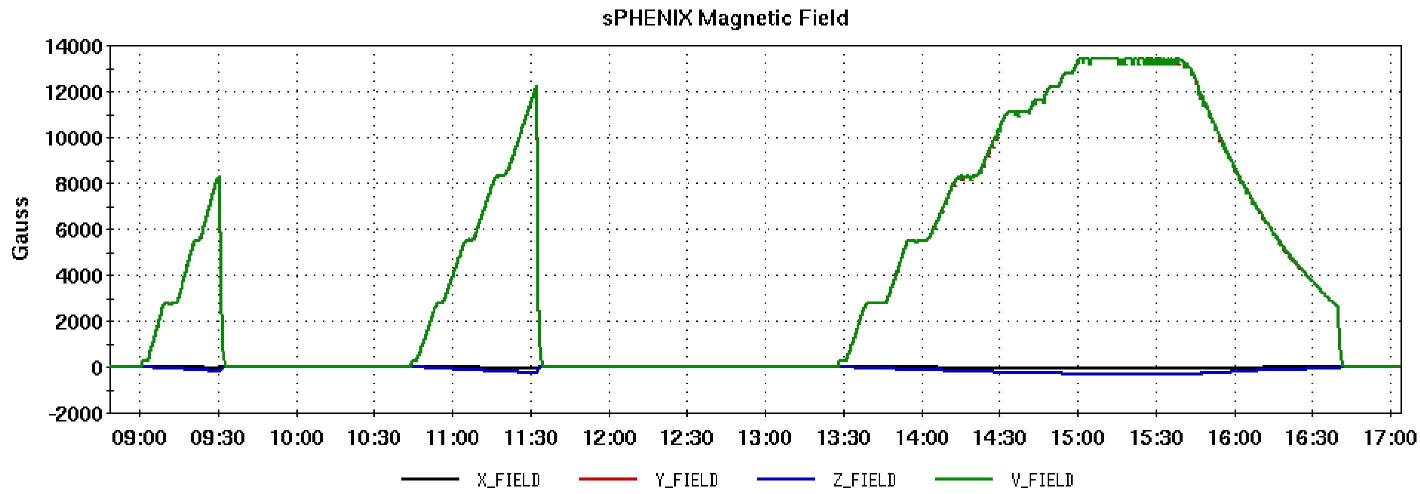
You may look at my sPHENIX Magnet calendar :

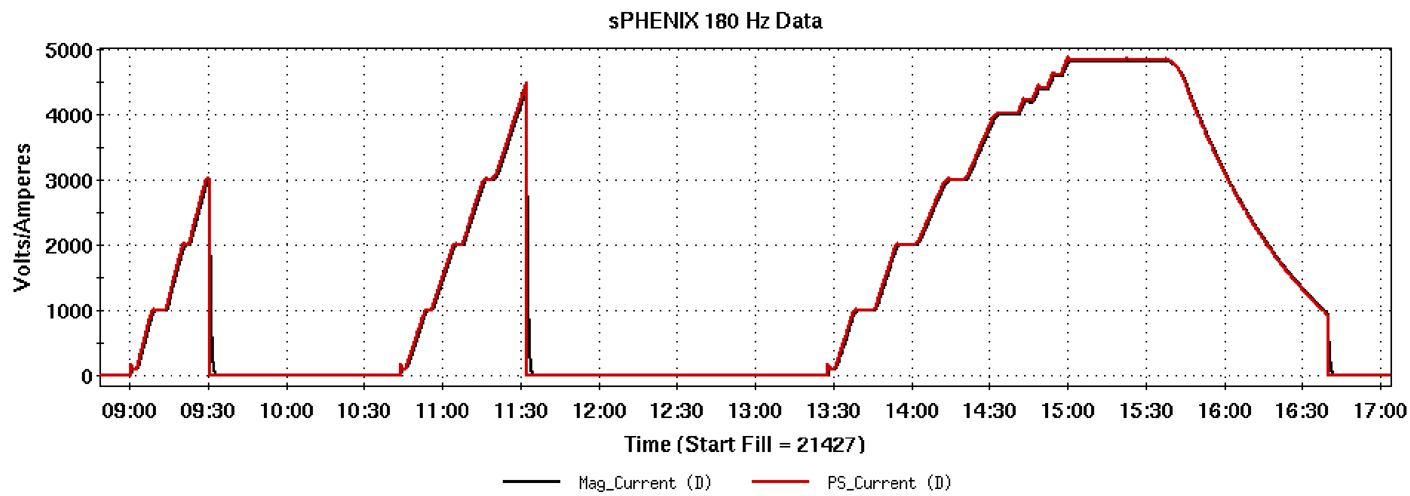
https://collab.external.bnl.gov/sites/sPHENIX-Magnet/Lists/Calendar/calendar.aspx

We started testing on Jan. 22, 2018. I think we've achieved all we need to do. It seems that we have come to an end of this Test. (Part of it is that people need to go to work on RHIC starting …)

Paul Orfin won't warm up today but he'd like to do so as soon as possible.

If anybody objects to the conclusion of this High-Field Test and think that we need to try more, please let us know before next Tuesday (Feb. 20, 2018).





4 Future Recommendation

Items to review for final installation at IP8

1. Current lead flow controllers need to be able to operate at a lower pressure drop
   a. MKS units were losing feedback at low pressures at 912 facility
   b. Using MKS units in parallel would lower the pressure drop and increased flow capacity
   c. Consider using Alley Cat flow meters
   d. Review existing piping and see if there are any other flow/pressure restrictions
2. Current leads heaters: locate to flange where the frost is and new mounting piece to transfer the heat. Review location of the temperature sensor that controls the heater.
3. The coax line had a large pressure drop across it
   a. Coax was not part of IP8 installation plan but high dP relevant for any future uses of this line.
   b. Issue may be with the transition at the solid piping section or with repair made to bayonet tips at valve box end

4. Increase flow through shield
    a. Initial single MKS flow meter was not able to supply more than 0.65 g/s
    b. Two units in parallel were able to double the flow with less pressure drop
        i. 1.2 g/s at 1.3 atm
    c. The configuration for IP8 install will be different: the shield flow returns cold in series with the cryo transfer bundle shield. We will have an Sierra thermal mass flow insertion meter after the heater going to the WR.
5. Internal Leak inside of Valve box or solenoid
    a. 1.2x10^-5 Torr-L/sec measured while cold at end of high power test
    b. Ray Ceruti's test from before low power test isolated leak to be somewhere in the piping of the vertical valve box chimney
    c. Vacuum system was able to maintain good insulating vacuum during testing with Turbo molecular pumps.
6. Improve temperature sensor mounting for splice joints
    a. Stack up layers on temperature sensors may be high and G-10 plate may be influencing temperatures
    b. Provide a physical mount for the sensors
7. Consider adding vent for new splice joint loop
    a. Splice loop can trap gas and increase pressure drop
    b. Vent line would need to go from top of joint and route up to top of phase separator
8. Review level probes in valve box phase separator
    a. Probes read somewhat erratically
    b. Consider adding a shroud around them to limit splashing or cold vapor influence
9. Consider replacing the vacuum system
    a. Most components were from the original test and have may hours on them
    b. Roughing pumps failed twice during low and high-power testing, replacements were installed till the pumps could be repaired
10. Warm up procedure should recommend temperature drift over forced warm up
    a. Recommendation from January 2018 cryogenic review
11. The cables length for IP8 will be longer than 100ft.
    a. Get Lakehsore 224 unit for the Cernox sensors to handle high capacitance wires.
    b. Review wiring length for the CLTS sensors / Strain gage sensors

5 References:

[1] J. Muratore, P. Joshi, K. Yip, "Low Field Test of sPHENIX Solenoid Magnet", May 2017 : https://collab.external.bnl.gov/sites/sPHENIX-Magnet/Shared%20Documents/100%20A%20Test/2017-5-5%20Low%20Field%20Test%20of%20sPHENIX%20Solenoid%20Magnet%20-%20Tech%20Note.docx

[2] dfkjdkfjd