Mu2e: Temperature Stabilization of the Calibration Magnet Water Cooling Circuit

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This report discusses the changes made to the water cooling circuit for the purpose of stabilizing the temperature of the calibration magnet that will be used in the calibration of the Hall probes to be used in the detector solenoid (DS) of the muon-to-electron (mu2e) experiment at Fermi National Accelerator Laboratory (Fermilab) during the summer of 2017. After implementing the changes, the temperature of the water and magnet stabilizes with a current of 200 ADC yielding a 1.07 T magnetic field which is just below the desired value. This report mentions future plans to prevent overheating and automate monitoring and adjustment processes. The attached slides at the end of this report serves as visual aides to the changes made as well as enlarged versions of the figures in the report.

1. PROJECT GOAL

The mu2e experiment at Fermilab requires very precise measurements. This requires that the Hall probes used for the experiment are calibrated uniformly at a very high precision. For the calibration process, Metrolab NMR probes and Teslameter were used to measure the absolute magnetic field at a given area inside the field region being observed. The goal of the calibration was to define an area of magnetic field uniformity in the accuracy of 10^{-5} T between 1.2 T and 1.4 T. The magnetic field was produced by an electromagnet and was powered by an ADC power supply. Upon initial test runs at low current, it was observed that the magnetic field produced and the power supply output were drifting over time due to temperature. Initial attempt to solve this involved using the water cooling system put in place to minimize the thermal variations in the temperature of the system. However, the calibration magnet overheated when run at higher currents needed to achieve the magnetic field desired. As such, preventing the magnet from overheating took precedence over minimizing thermal variation on the system.

2. INITIAL PLAN

The diagram above shows the schematic for the old water cooling circuit. In this system, the deionized water goes through the main power supply (orange). At the return pipe, a valve was used to bypass the sweeper magnet (blue) and divide the water flow between the calibrator magnet and the power supply running it. The outlet for the calibrator and its power supply then goes through the sweeper magnet and through the heat exchanger before going through another cycle. The diagram below shows the proposed changes to the system followed by detailed description of each change.

![Old Water Cooling System](image1)

![Proposed Water Cooling System](image2)

Figure 1 – Old Water Cooling System

Figure 2 – Proposed Water Cooling System

The first change included in the initial proposed solution was changing the pipe size right before the flow switch. It was observed that there were differences in the pipe diameters before and after the flow switch, and it was theorized that making the pipe size in this area uniform will provide a more constant water flow. The flow switch broke during the removal process and it was later decided to bypass this switch as it was not necessary at the time. As for majority of the pipe work, new inlet and outlet pipes had to be created for the water flow. At the same time, the team was interested in checking if the water flow and water pressure stays constant or at least have minimal drop from one point to the next. As such, the pipes were
equipped with recycled ends for quick connects/disconnects. The new pipes above the main power supply were also mounted on a steel bar as opposed to have them suspended in the air similar to how it was prior to the changes. The water heater was also installed but was not powered because it was not deemed necessary.

After the pipe work was done the magnet was tested with the power supply at 360 ADC and the magnet overheated. It was originally thought that the magnet was not getting enough water flow per the requirements given in the company specifications for the magnet. It was determined later that a broken device was giving the wrong measurements and that the magnet was getting enough water flow. In order to distribute water evenly across the magnet, the inlet pipe was divided so that water flows in parallel across both magnet coils. The magnet company also stated that the maximum current that can be run for this experiment was 280 ADC.

3. IMPLEMENTATION

The magnet was once again tested on 280 ADC but it still overheated. The current was lowered until overheating was prevented. At 126 ADC, the magnet did not overheat. The magnetic field readings were about 0.7 T which was below the desired value of 1.2 T – 1.4 T. However, a full mapping was processed in order to get a general idea of the shape of the magnetic field region.

When checking the physical temperature of the magnet during mapping, it was observed that the left coil is heating up more than the other coil as shown in Figure 3 below.

A PLC was also installed to monitor the water temperature automatically. Three K-type thermocouples were put in the following places: one right after the heat exchanger going into the barrel of deionized water; one right after the pump before going through power supply; one right before the heat exchanger after the magnet. Additionally, an actuator was also added to control the flow of cooling water in the heat exchanger.

4. FINDINGS

After implementing the changes, the magnet still overheats when currents greater than 200 ADC are used. At 200 ADC, the magnet does not overheat while yielding a magnetic field of approximately 1.07 T which is just below the desired value. The water temperature appears to stabilize after 2-3 hours of the magnet being turned on.

5. FURTHER DEVELOPMENTS

A second heat exchanger was installed to re-cool the water coming in through the magnet in an attempt to prevent overheating at 250 ADC. Upon testing, however, the magnet still overheated. A thermal image of the two coils shown below shows that the coil that gets the cooling water first is warmer than the second coil that gets warmer water. This has led to the conclusion that the water cooling system is not the problem causing the overheating. Further investigation showed that the overheating magnet had abnormal heat patterns: (1) the middle cooling pipe is significantly warmer than the other two; (2) there are significantly warm areas on the plate that seem to jump out of the temperature gradient; (3) the overall temperature of the coil is different when looked from one side to the other. It was also observed that there

![Figure 4 – Temperature Readings, 200 ADC](image-url)

![Figure 3 – Temperature Readings, 126 ADC](image-url)
are gaps in the plates on the coil that may be caused by thermal expansion.

6. FUTURE PLANS

Additionally, the PLC is planned to be utilized to control the initial temperature of the water cooling circuit in the barrel. There are also plans to automate the recording of temperatures from old and new thermocouples including the PLC and handheld measurement devices. Two thermocouples are also planned to be attached to monitor the temperature of the magnet. Lastly, the heater installed will later be powered to stabilize the temperature once overheating is prevented.
Temperature Stabilization of the Calibration Magnet Water Cooling Circuit

Emmanuel Aldana
Summer Project Presentation
17 August 2017
Agenda

- Mu2e
- Experiment
- Objectives
- Findings
- Future Plans
Background

Mu2e focuses on two elementary particles:
- Muon
- Electron
Most common muon-to-electron decay is as follow:
Background

Charged Lepton Flavor Violation:

- Certain families can change flavors (quarks, neutrinos)
- Why can’t leptons?
  - Theorized, but not observed
  - Observing whether or not they change will lead to new physics beyond the standard model
Mu2e Experiment

Search for direct conversion of muon to electron (CLFV)

- Housed in Fermilab to reuse parts of accelerator complex used for Tevatron
Mu2e Experiment
Mu2e Experiment

Production Solenoid → 8 GeV proton beam → Detector Solenoid

Transport Solenoid
Mu2e Experiment

Production Solenoid

8 GeV proton beam

Transport Solenoid

Detector Solenoid

4.6 T  2.5 T  2 T  1 T  1 T
Mu2e Experiment

Production Solenoid

Transport Solenoid

8 GeV proton beam

Tracker

Detector Solenoid

Calorimeter

4.6 T

2.5 T

2 T

1 T

1 T
Mu2e Experiment
Detectors need to be accurate – and calibrated using NMR/Hall probes

Hall probes have to be calibrated. Magnet will be used for calibration using NMR probes

Calibration needs to be very accurate ($<10^{-5}$ T) for uniform homogeneity

Calibration needs to be repeated for different currents
Calibration Magnet

GMW 3474-240/280 250mm electromagnet
Power Supply

Danfysik
System 8000
Up to 360 ADC

Power Energy
Industry SR1029
Up to 5000 ADC
NMR Probe and DMM

Metrolab Teslameter PT

2025 NMR Probe

HP 3458A
Magnetic Field Mapping

Magnetic field values were measured and plotted on specific probe locations.
Water Cooling

Power supply and calibration magnet have to be water cooled to stabilize temperature and prevent overheating.
Water Cooling Circuit (Old)
Problem

Magnet overheated when using 360 ADC

Temperature change over time caused magnetic drift and inconsistent readings

Magnet takes about 2.5 hours to reach stabilized temperature on low currents.

Objective for the summer
- Prevent magnet from overheating so data can be taken at desired currents
- Speed up the stabilization of magnet temperature and the power supply output
Water Cooling Circuit (Plan)
Changed pipes, but flow switch broke
Installed quick connects/disconnects
Bypassed the orange power supply
Bypassed the orange power supply
Water flow checked, magnet thought to not get enough flow
Magnet pipes put in parallel
Magnet did not overheat at 126 ADC (~0.7 T)
Magnet did not overheat at 126 ADC (~0.7 T)
Magnet did not overheat at 126 ADC (~0.7 T)
Magnet pipes put in series, again
Magnet did not overheat at 200 ADC (~1.07 T)
Water Cooling Circuit (PLC installed)
Siemens S7-1200
Water Cooling Circuit (Current)
Findings

Water flow and pressure for the magnet consistent with company parameters

Magnet, water temperatures stabilizes after 2-3 hours. Power supply stabilizes after 8 hours.

Magnet temperature is also affected by ambient temperature

There are discrepancies in temperatures from old and new thermocouples
Future Plans

Throttle valve + actuator to stabilize the temperature of the cooling water in the barrel

Install second water heater to cool water again prior to entering the magnet

Automate monitoring of all water thermocouples using Siemens PLC/Omega Thermometer

Include two thermocouples to monitor temperature of the magnet

Power up heater to stabilize water temperature once overheating is prevented
Program Takeaways

Science can take a long time

Advancement of science is hindered by availability of technology

Communication and proper planning is a necessity in research involving multiple parties

Particle physics is an interesting topic, and not as confusing after multiple exposure
Questions?