# Power and LCW Estimates for the Neutral Particle Spectrometer Sweeper Magnet

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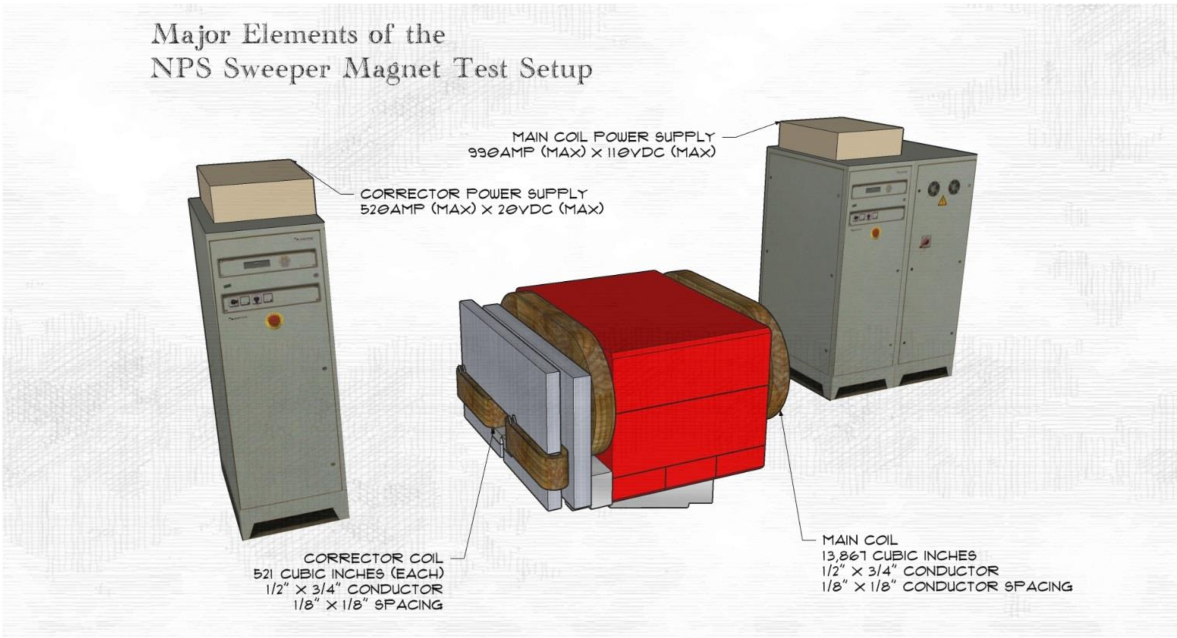


*Figure 1. NPS Sweeper Magnet Test Configuration*

## I. INTRODUCTION

This document provides an estimate for the resources that will be used to run the Neutral Particle Spectrometer at full field for testing in Jefferson Lab's Test Lab. As I have some uncertainty about how these values should be derived, I've provided an exhaustive description of how the calculations and estimates were made so that others can review them for accuracy. At a fundamental level, the results that were derived from these calculations are relatively close to the original estimates for low conductivity water (LCW) usage that were provided by Bogdan Wojtsekhowski and Jack Segal *(they estimated a total LCW requirement of 17 gallons per minute for the magnet).*

The following sections will compute the resistance of each of the coils based on the length and cross sectional area of the conductors. That value, in concert with the stated power supply characteristics, will be used to compute the power consumption using Ohm's Law. This value is then used to compute thermal load and cooling requirements using the standard formulas.

## II. MAIN COIL CALCULATIONS

### Main Coil Conductor Length

*Conductor length is computed using the computed volume of the entire coil divided by the computed volume of 1 linear inch of conductor. Note that the thickness of the epoxy surrounding the conductor must also be included to obtain an accurate length.*

a. Main coil volume (computed from model):
   13,867 cubic inches

b. Volume of 1 linear inch of raw conductor (by visual inspection):
   (1/2)(3/4)(1) = 0.375 cubic inches

c. Volume of 1 linear inch of conductor with epoxy (by visual inspection):
   (1/2+1/8)(3/4+1/8)(1) = 0.547 cubic inches

d. Length of conductor in main coil:
   13,867 / 0.547 = 25,351 inches

### Main Coil Resistance

*Resistance is computed using the resistivity of the material, the length of the conductor, and the cross sectional area of the conductor, such that*

*resistance = resistivity * length / area*

a. Length of the conductor:
   25,351 inches (643.9154 meters)

b. Cross sectional area of the conductor:
   0.375 square inches ($2.41 \times 10^{-4}$ square meters)

c. Resistivity of copper:
   $1.72 \times 10^{-8}$ Ohm meters

d. Resistance of main coil:
   $(1.72 \times 10^{-8})(643.9154)/(2.41 \times 10^{-4})=0.0460$ Ohms

### Main Coil Power Consumption

*Given Ohm's Law, power loss due to resistance within the magnet coil is computed using the voltage (V), the current (I) and the resistance (R), such that I=V/R or V=IR. Assuming that both the voltage and the amperage of the power supply can be adjusted, the maximum power loss due to resistance can be computed as follows.*

a. Computed Current Using Maximum Voltage
   Voltage = 110 Volts
   Resistance = 0.0460 Ohms
   Current = 110/0.0460 = 2,394 Amps

   *Note: Since the computed current exceeds the maximum current available, the voltage must be derived using the maximum current.*

b. Computed Voltage Using Maximum Current
   Current = 990 Amps
   Resistance = 0.0460 Ohms
   Voltage = 990 * 0.0460 = 45.496 Volts

c. Power Consumption Due to Resistance
   Watts = 45.496V * 990A = 45,041 Watts

### Main Coil Heat Generation

*Heat generation is derived using the power consumed in watts and is computed as both British Thermal Units (BTUs) and HVAC tons.*

a. BTU Calculation
   BTU = 45,041 Watts * 3.412 = 153,681 BTUs

b. HVAC Tonnage Calculation
   Tonnage = 153,681 BTUH / 12,000 = 12.81 tons

### LCW Requirement for Main Coil

*Cooling water demand is computed using the amount of heat being dissipated (in BTU) and the change in water temperature due to heat exchange (ΔT – given in degrees Fahrenheit), such that:*

*BTU = 500 * GPM ** ΔT or

*GPM = BTU / (500 ** ΔT)

a. Computed Cooling Water Requirement
   ΔT in Test Lab = 14° F
   Heat to be Dissipated = 153,681 BTU
   GPM = 153,681 / (500 * 14) = 21.95 GPM

## III. CORRECTOR COIL CALCULATIONS

### Corrector Coil Conductor Length

*Conductor length is computed using the computed volume of the entire coil divided by the computed volume of 1 linear inch of conductor. Since there are two coils on the corrector, the volume of the corrector coil is doubled from 521 to 1042 cubic inches for this calculation.*

a. Corrector coil volume (computed from model):
   1,042 cubic inches

b. Volume of 1 linear inch of raw conductor *(assumed to be the same as the main coil)*:
   (1/2)(3/4)(1) = 0.375 cubic inches

c. Volume of 1 linear inch of conductor with epoxy *(assumed to be the same as the main coil)*:
   (1/2+1/8)(3/4+1/8)(1) = 0.547 cubic inches

d. Length of conductor in corrector coil:
   1,042 / 0.547 = 1,905 inches

### Corrector Coil Resistance

*Resistance is computed using the resistivity of the material, the length of the conductor, and the cross sectional area of the conductor, such that*

*resistance = resistivity * length / area*

a. Length of the conductor:
   1,905 inches (48.387 meters)

b. Cross sectional area of the conductor:
   0.375 square inches ($2.41 \times 10^{-4}$ square meters)

c. Resistivity of copper:
   $1.72 \times 10^{-8}$ Ohm meters

d. Resistance of corrector coil:
   $(1.72 \times 10^{-8})(48.387)/(2.41 \times 10^{-4})=0.00345$ Ohms

### Corrector Coil Power Consumption

*Given Ohm's Law, power loss due to resistance within the magnet coil is computed using the voltage (V), the current (I) and the resistance (R), such that I=V/R or V=IR. Assuming that both the voltage and the amperage of the power supply can be adjusted, the maximum power lost due to resistance can be computed as follows.*

a. Computed Current Using Maximum Voltage

   Voltage = 20 Volts
   Resistance = 0.00345 Ohms
   Current = 20/0.00345 = 5,791 Amps

   *Again, since the computed current exceeds the maximum current available, the voltage must be derived using the maximum current.*

b. Computed Voltage Using Maximum Current

   Current = 520 Amps
   Resistance = 0.00345 Ohms
   Voltage = 520 * 0.00345 = 1.794 Volts

c. Power Consumption Due to Resistance

   Watts = 1.794V * 520A = 933 Watts

### Corrector Coil Heat Generation

*Heat generation is derived using the power consumed in watts and is computed as both British Thermal Units (BTUs) and HVAC tons.*

a. BTU Calculation

   BTU = 933 Watts * 3.412 = 3,183 BTU

b. HVAC Tonnage Calculation

   Tonnage = 3,183 BTUH / 12,000 = 0.27 tons

### Low Conductivity Water Requirement for Corrector Coil

*Cooling water demand is computed using the amount of heat being dissipated (in BTUs) and the change in water temperature due to heat exchange (ΔT – given in degrees Fahrenheit), such that:*

$BTU = 500 * GPM * \Delta T$ or

$GPM = BTU / (500 * \Delta T)$

a. Computed Cooling Water Requirement

   ΔT in Test Lab = 14° F
   Heat to be Dissipated = 3,183 BTU
   GPM = 3,183 / (500 * 14) = 0.45 GPM

## IV. POWER SUPPLY CALCULATIONS

It is assumed that inefficiencies in the power supplies during transformation will result in a loss of around 20%. This suggests that the LCW requirements for the power supply can be computed as follows:

a. Power Consumed at Power Supply

   45,974 Watts * 0.20 = 9,194.8 Watts

b. BTUs to be Dissipated

   9,194.8 Watts * 3.412 = 31,372 BTU

c. Gallons of Cooling Water Required

   GPM = 31,372 / (500 * 14) = 4.48 GPM

## V. TOTAL RESOURCE USAGE

Based on the size of the coils, the calculated resistance and the estimated losses due to inefficiencies in power transformation, the following resource projections can be made:

a. Power Consumed at Full Field = 55,168 Watts
b. Heat Generated at Full Field = 188,236 BTU
c. LCW Required at Full Field = 26.89 GPM

## VI. CONCLUSION

According to Carrol Jones of Facilities Management, the total capacity of LCW that is available on the north end of the Test Lab is 80-100 gallons per minute. The main consumers of this LCW are the Upgraded Injector Test Facility (UITF) and the Cryomodule Test Facility (CMTF).

If testing is conducted in coordination with the other consumers in the Test Lab, it is possible that the NPS magnet may be tested at full field for a limited amount of time. If the UITF and CMTF are in operation, it is likely that the available LCW would be limited to around 17 gallons per minute. While this is not enough to perform full field testing, it would allow the magnets to be operated at around 60% of their capacity *(assuming a linear relationship between power and capacity).*

Again, these estimates are based on generalized formulas and are offered for planning purposed only. Actual power and cooling consumption may vary significantly depending on the efficiency of the power supplies and idiosyncrasies of the magnet.