DRIFT TUBE LINAC (DTL) STEERING MAGNETS REPLACEMENT DESIGN AT SNS*

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Abstract

The SNS Drift Tube Linac (DTL) operates at 402.5 MHz and consists of 6 RF tanks, DTL1 to DTL6, which accelerate the H- beam from 2.5 MeV to 87 MeV before entering the Coupled Cavity Linac (CCL). Each DTL tank assembly has 2 sets of horizontal and vertical electromagnetic steering magnets (24 in total) required for transverse beam steering. The steering magnets are water-cooled copper tubing coils designed to fit in the limited space inside the drift tube bodies. After 20 years of operation, some of the copper tubing steering coils have developed water leaks likely due to elevated water flow velocities. For the leaking coils, the cooling water has been removed and the steering coils have been disabled. The water leak points are inaccessible for repair so the entire drift tube will require replacement to be able to restore the electromagnet. To prepare for the possibility of drift tube replacement in the future design and fabrication of spare drift tubes is underway, including ones with steering magnets. To simplify the steering coil winding and avoid water leaking issues, a non-water-cooled steering magnet design has been developed. With the existing yoke, the new coils are designed to produce the same magnetic field with lower electrical power removing the need for water cooling. According to the CST [1] simulations, the maximum temperature of the coils is below 50°C with no water cooling. A prototype development is in progress and will be used for thermal testing and magnetic field verification. Details of the steering magnet design and calculation results are presented in this paper.

INTRODUCTION

The Spallation Neutron Source (SNS) Drift Tube Linac (DTL) tanks employ four distinct types of drift tubes to accelerate and control the H- beam [2]. Among these, the Permanent Magnet Quadrupole (PMQ) drift tubes utilize 16 permanent magnets to provide transverse beam focusing with a gradient of 3.70 kG/cm. Additionally, some drift tubes are empty, constructed of solid copper, while others incorporate Electromagnetic Dipoles (EMDs) for beam steering or Beam Position Monitoring (BPM). Each DTL tank assembly has 2 sets of the “x” and “y” EMD steering magnets. Two Drift tubes downstream of the EMD Drift tubes house a BPM, which will provide beam location feedback [3].

The current EMD magnets feature a carbon steel yoke and water-cooled copper coils encapsulated in epoxy, designed to fit within the drift tube bodies. This existing design involves complex and costly winding of copper tubing and necessitates additional water-cooling circuits. Unfortunately, this design has experienced issues with water leaks after 20 years of operations, with two incidents reported in the past a few years: one in DTL2 in 2020 and another in DTL3 in 2023. Although these leaks did not affect the cavity pressure because they are outside the vacuum, we need to remove the water cooling and disable these steering coils, and retore the beam operation by adjusting other beamline steering magnets. To address these issues, a new design featuring solid copper wire magnet without water cooling has been proposed.

EXISTING EMD COILS

As the first step of the new coils design, we developed a CST model of the existing EMD vertical steering magnet (see Fig. 1) to calculate the field distribution as a reference. Table 1 shows EMD magnet requirements of DTL3 as an example in this paper.

Table 1: Required Field Strength of EMD in DTL3

Steel Length	Gap	Current	Steering Field
2.88 cm	2.83 cm	110 A	560 Gs-cm

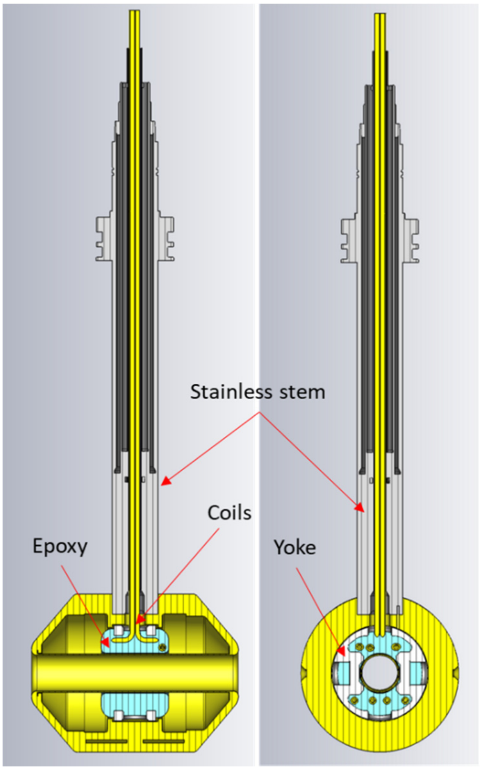

Figure 1: CST model of the DTL3 EMD magnet.

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The EMD yoke was constructed from Steel-1010, with a longitudinal length of 2.88 cm and a pole gap of 2.83 cm. For the coil winding, 3/16-inch copper tubing was used. Due to space constraints, the coil was designed with only four turns in total, two turns per pole. Both the steel yoke and coil windings have been adapted to fit within the limited space of the drift tube bodies, as shown in Fig. 2. To achieve the desired magnetic field with this 4-turn coil, a coil current of 110 A is needed, and water cooling is required to dissipate the generated heat. The EMD drift tubes have two separate water-cooling circuits: one for the drift tube body and another specifically for the copper coils. The magnetic field for the current EMD design was calculated using the CST M-Static solver, revealing a maximum dipole field strength of over 200 Gauss at 110 A. The total thermal power loss of the coils is approximately 26 W.

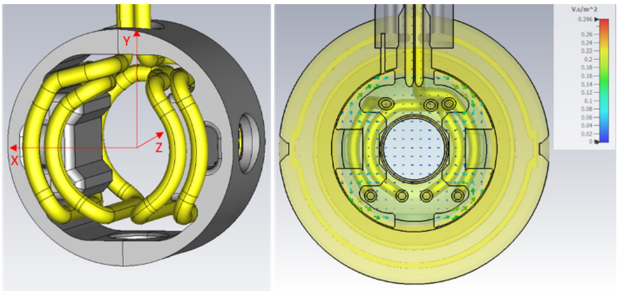

Figure 2: EMD yoke & coils (left) and magnetic field calculation (right).

NEW COILS DESIGN

The new EMD magnet design will retain the original yoke configuration but will be modified to enhance thermal contact with the drift tube bodies. After comparing the maximum allowable number of turns and heat power with different wire types and sizes, we selected 1 mm diameter solid copper wire with an insulated Polyetheretherketone (PEEK) coating, which provides superior thermal resistance. The new coils feature 72 turns (36 turns per pole), compared to the existing design with 4 turns. Figure 3 show the new steering coil winding and magnetic field distribution with CST M-Static simulation.

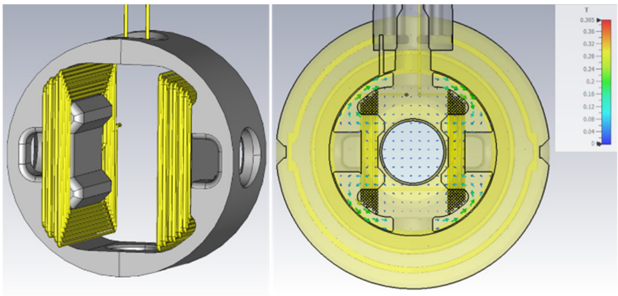

Figure 3: New EMD coils (left) and magnetic field calculation (right).

This design simplifies the winding process and reduces the current requirement to 6 A to achieve the same magnetic field strength as the current water-cooled coils, which require 110 A. Figure 4 shows the new coils generate a comparable magnetic field gradient along the beam axis comparing to the current magnet. The field profile in Fig. 5 exhibits an improved uniformity in the X direction comparing to the existing one.

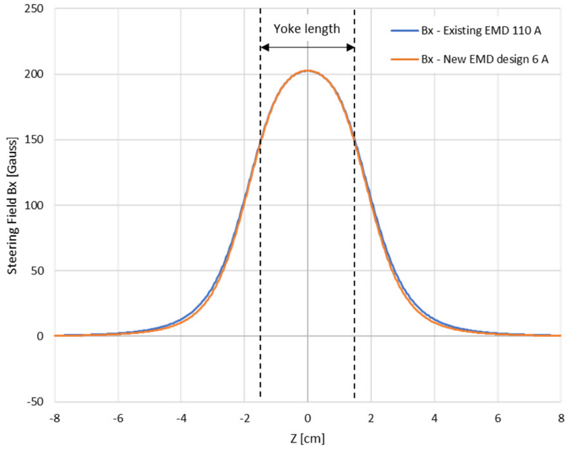

Figure 4: Gradient along the beam axis of the new coils vs. the existing magnet.

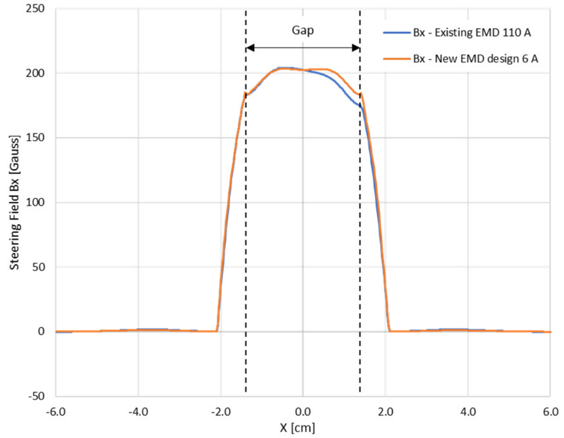

Figure 5: Gradient along the X direction of the new coils vs. the existing magnet.

THERMAL ANALYSIS

Thermal performance of the new EMD magnet was evaluated using CST Design Studio. The analysis involved calculating thermal losses of the coils with the CST Stationary Current Solver and then importing these losses for steady-state thermal simulations. Thermal surfaces of the water channel and air contact were set up with convective heat transfer coefficient value which was pre-calculated before the simulation. Figure 6 shows detailed structure of the new EMD simulation model.

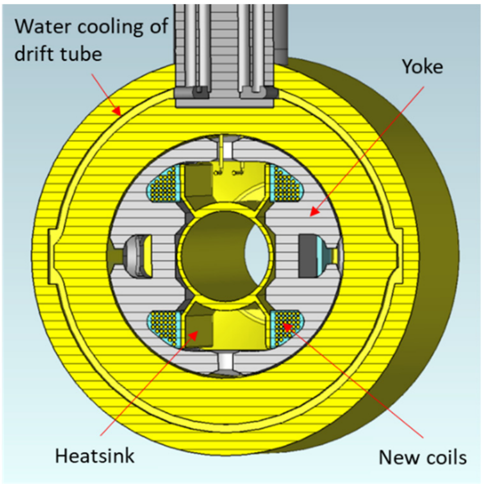

Figure 6: New EMD thermal model with heatsink.

Cooling was applied only to the drift tube bodies, maintaining a water temperature of 25°C. The coils and yoke do not have direct water cooling but benefit from effective thermal contact through epoxy encapsulation and a heatsink design on the core tube. Simulation results indicate that, under a 6 A current, the maximum temperature of the coils reaches 47°C (320 K, see Fig. 7), which is acceptable for nominal operation.

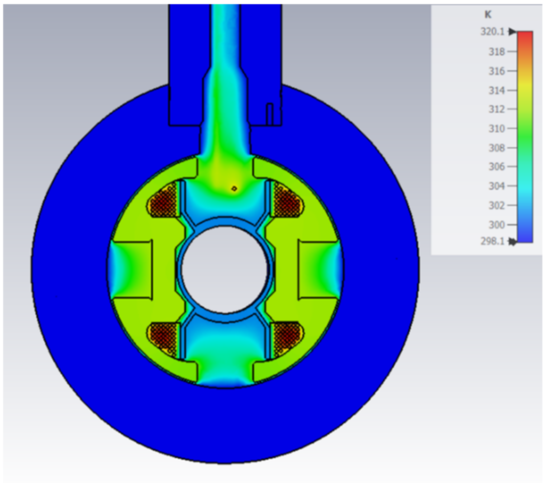

Figure 7: Thermal simulation result.

Currently, the yoke is secured by eight small pins, and there is a 0.5 mm gap between the yoke and the inner surface of the drift tube body. To enhance thermal conduction, we plan to improve the yoke housing design to achieve better contact. Further simulations will be conducted to evaluate the impact of these improvements on thermal performance.

In parallel, a prototype of the new EMD magnet is under development. The yoke of this prototype has been redesigned to simplify the fabrication process. Additionally, to accurately monitor the temperature distribution, thermocouples will be installed on both the coil and yoke surfaces. These measurements will be tested and validated on the prototype.

SUMMARY

A new EMD magnet design, eliminating the need for water cooling, has been developed as a potential future replacement for the existing EMDs. This design provides similar magnetic field gradients and demonstrates improved thermal performance based on CST simulations. A prototype is currently being developed to undergo magnetic field measurement and thermal testing. Additionally, future considerations include exploring air-cooling solutions to accommodate higher current operations if necessary.

ACKNOWLEDGEMENTS

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