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[Fri-Af-Po.03-04] The design and performance of the Canis 3x3 magnet array support systems

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Introduction

Thea Energy, Inc has designed, developed, and tested the "Canis" 3x3 array of high-temperature superconductor (HTS) planar coils, which will serve as a prototype for the development of the "Eos" planar coil stellarator[1]. The support systems were designed, developed, and deployed to enable the successful operation and test of the Canis 3x3 magnet array.

Design

The Canis 3x3 magnet array consists of 9 superconducting HTS coils. The support systems consist of a vacuum vessel, a radiation shield, first and second stage cooling systems, a magnet current distribution system, and a mechanical support structure.

Vacuum System

- 4000L cryostat vacuum vessel was recommissioned from an aluminum vessel which had been previously used in cosmic-ray detection experiments at Mt. Evans in the 1960s [2]
- Contains experiment and maintains vacuum environment
- 1×10^{-5} Torr vacuum pressure required for cryogenic systems

First Stage Cooling System

- The first cooling stage is cooled to 80 by a liquid nitrogen (LN2) distribution system
- Cools gravity supports, first stage current leads, and radiation shield
- LN2 distribution system has an estimated cooling power of 17.8 Kilowatts

Second Stage Cooling System

- Second cooling staged is cooled to a temperature of 20 K by a 20 bar supercritical helium (ScHe) cryoplant and distribution system
- Cools magnet array and second stage current leads
- Magnets are cooled conductively using spiral cooling plates with internal helium cooling channels
- ScHe flow is driven by a cryofan in the ex-vessel cryoplant
- The cooling plant was measured at Thea Energy to have a total cooling power at 20 bar and 20K of 325 W

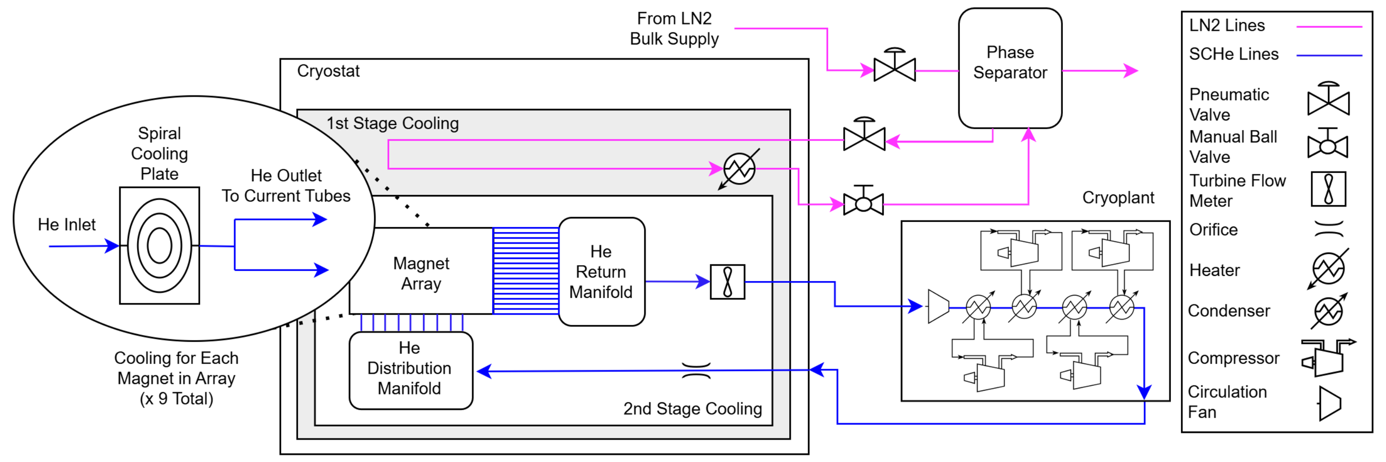

Figure 1. Simplified fluid network diagram, showing major components of LN2 and ScHe systems [1]

Current Distribution System

- The nine magnets in the array are powered by nine independent Magna Power SL10-250 DC power supplies
- Resistive copper wires supply power from cryostat flange to the first stage where they are cooled to 80 K by LN2 cooled copper blocks
- HTS leads carry power between the first stage and second stage. HTS is used here to reduce head load on the second stage from conduction and joule heating
- Current is carried from the HTS leads to the magnets using C101 copper current tubes, which also serve to carry the return flow of ScHe from the magnets

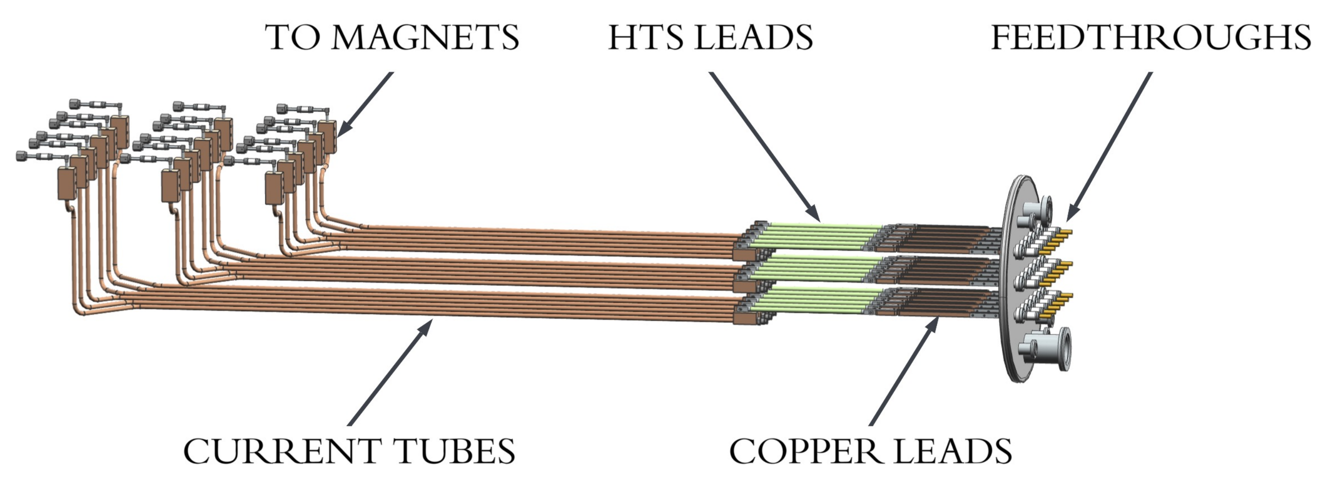

Figure 2. CAD rendering of hybrid HTS-copper in-vessel current leads [1]

Mechanical Support Structure

- SS316 structural plate with lateral stiffener bars supports the magnet array and is cooled by the second stage cooling system
- The structural plate was designed to tightly control deformation from gravity and magnetic loads on the coils and limit deflections to ±0.2 mm in order to maintain consistent magnet positions
- Structural plate is supported by G-10 standoffs which are attached to two parallel W10x12 SS316 beams which are cooled to 80 K using LN2 and mechanically support the in vessel cold mass

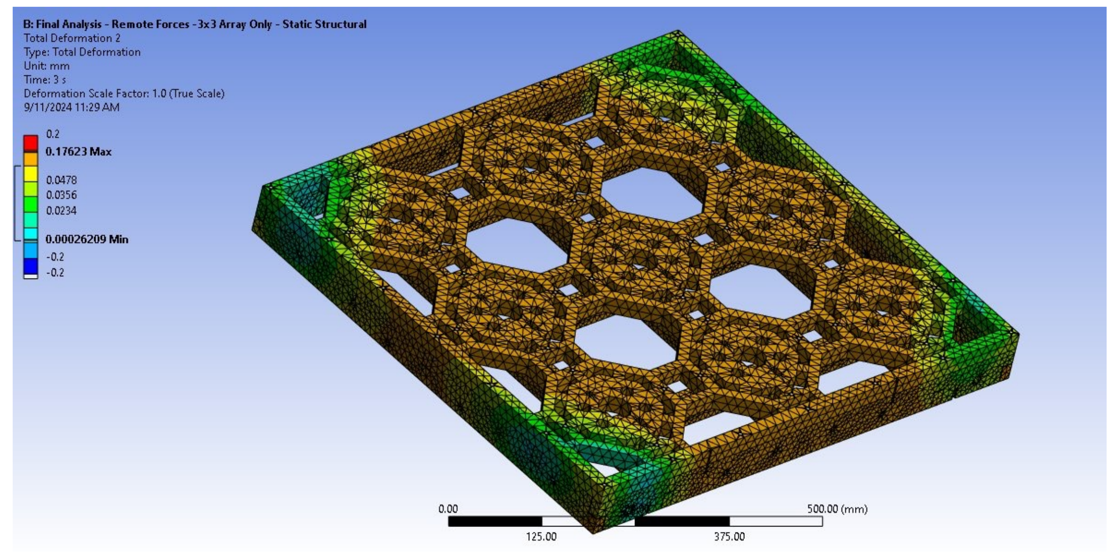

Figure 3: FEA simulation of total deformation from worst case Lorenz loading on magnet support plate

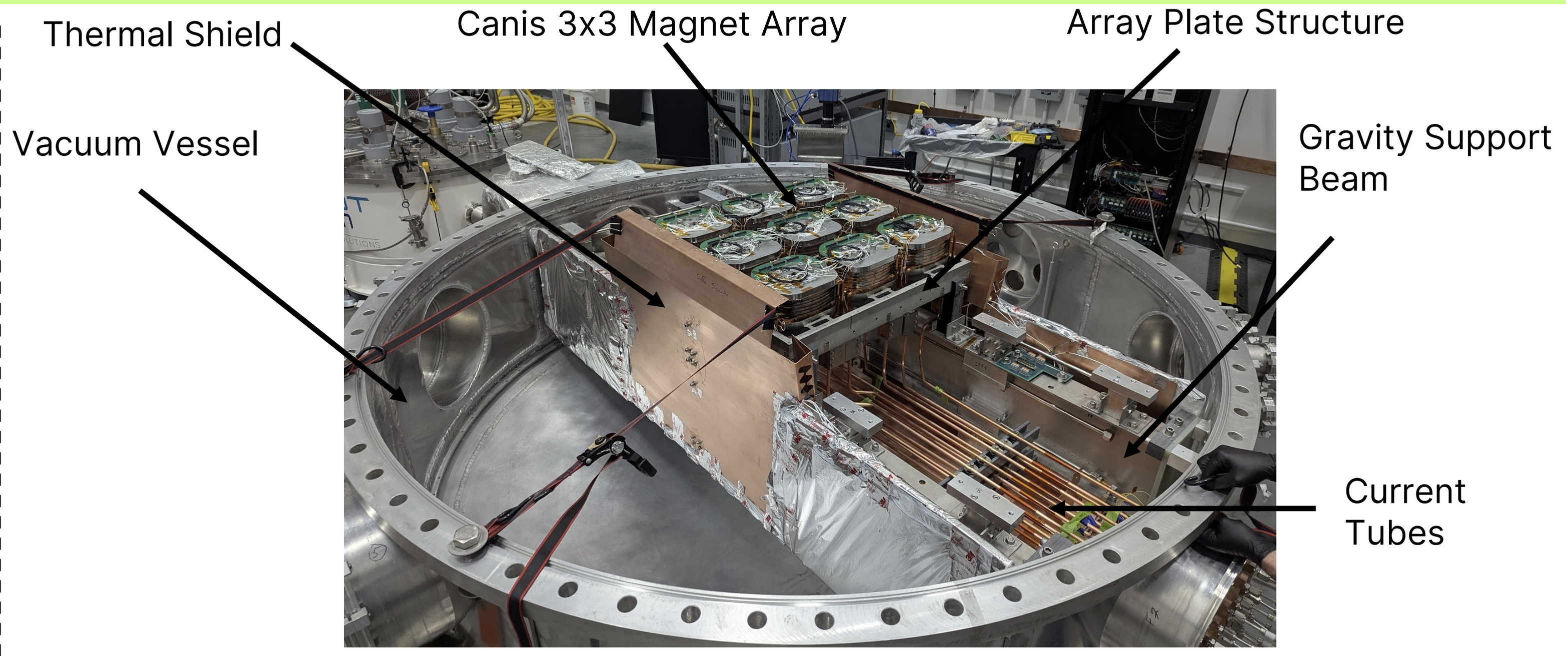

Figure 4. Installed magnet array

Table 1. Calculated heat loads on the first and second stage cooling systems

Source	First Stage Load [W]	Second Stage Load [W]
External Loads (Cryoplant, Transfer Lines, etc...)	111	46
Conduction through Supports, Feedthroughs and Instrumentation	25	12
Radiation	65	10
Current Leads (Steady State Joule Heating + Conduction)	122	6
Steady State Magnet Joule Heating	0	9
Total	323	83

Performance

Cooldown

- Prior to cooldown, the cryostat was purged several times with nitrogen gas and then pumped to a vacuum pressure of 1×10^{-5} Torr before operation of the cooling systems
- Temperature differential across the magnet array limited to <25 K
- The ScHe cooling system achieved a base temperature of <16 K,the operating temperature of 20 K was achieved using PID controlled heaters
- Total heat load on the second stage from in vessel sources was measured to be 25 W with the magnets unpowered and 35 W with the array at full current, roughly agreeing with predicted values

Table 2. Designed and measured fluid system flow rates

System	Designed [g/s]	Measured [g/s]
LN2	2.5	2.6
ScHe	18.0	18.1

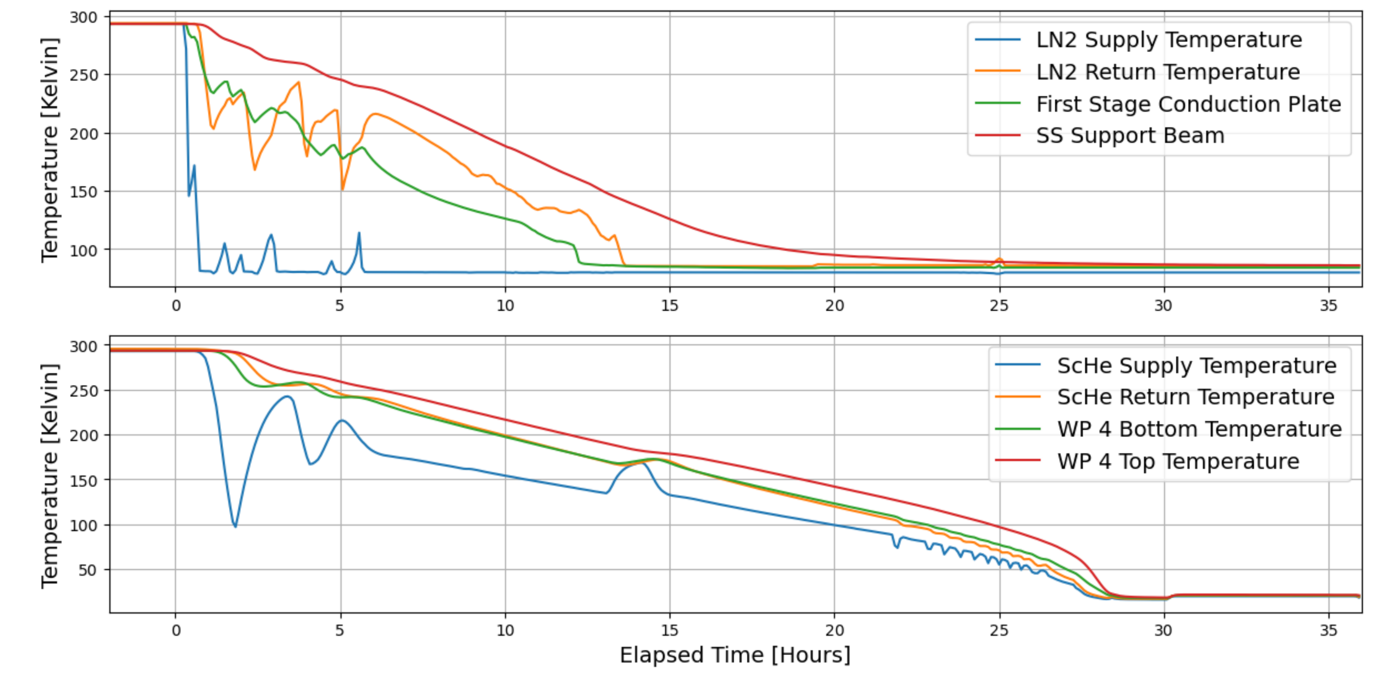

Figure 5. Cooldown plot showing first stage temperatures (top) and second stage temperatures (bottom)

Current Leads

- The current leads were successfully used to supply an operating current of 150 Amps for the test campaign. Additional testing at higher currents achieved close to 200 Amps before ultimately being limited by temperature increase on the first stage current leads
- Calculated and measured resistances across the current tubes give good agreement using an RRR value of 35

Test Campaign

- The Canis test campaign involved individual characterization of the nine magnets prior to characterization and calibration of the entire array
- After characterization and calibration, the calibrated array was used for open and closed loop field shaping to demonstrate multiple field shapes relevant to a planar coil stellarator as well as for testing the array in various quench scenarios
- These demonstrations required precise control and measurement of magnet temperatures and currents

Conclusion

The Canis test campaign successfully demonstrated magnetic field control using the Canis 3x3 magnet array. The Canis support systems enabled this demonstration by mechanically housing, providing a cryogenic environment, and supplying current to the Canis 3x3 magnet array. The support systems performance was well matched to the designed and predicted parameters. For future systems, ease of integration can be improved, and higher operating currents can be achieved through more effective cooling of first stage current leads.

References

1.Nash, D., Gates, D.A. et al. (2025). Prototyping and Test of the "Canis" HTS Planar Coil Array for Stellarator Field Shaping. https://arxiv.org/abs/
2.K. Erickson, "Multiparticle production in liquid hydrogen and carbon by charged cosmic ray hadrons of energy greater than 70 GeV," The University of Michigan, Technical Report UM HE 70-4, Apr. 1970.

2025 International Conference on Magnet Technology (MT29), July 1-6, Boston, MA
This work was funded by Thea Energy and performed as part of the DOE Milestone Based Fusion Development Program (DE-SC0024881).

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