SUPREME Plasma Thruster:
Cryogenic System Preliminary Design

Feroz T Khan, Cryogenics Engineer

NEUTRON STAR SYSTEMS

Abstract

The objective of this internship was to outline the preliminary design requirements for the cryogenics system to integrate into the "Applied-Field Module". This involved an extensive literature review of current state-of-the-arts while characterising various power cycles and succinctly defining the peripherals that coincide with cryogenics, through thermal modelling and simulation.

Introduction

Neutron Star Systems UK Ltd (NSS) is a space start-up pioneering the use of *High-Temperature Superconductors* (HTS) for spacecraft applications. NSS' main product is an exciting new electric propulsion technology. The SUPREME thruster is an *Applied-Field Magnetoplasmadynamic* thruster (AF-MPD), which has been researched globally for over 60 years but has been held back by the high mass of the electromagnets needed to generate the required magnetic fields. New technology utilising HTS magnets promise to overcome this issue and revolutionise the economics of space operations.

Three key advantages are offered by AF-MPD technology:

- Very low propellant costs
- Enormous scalability with minimal mass and volume penalties
- A wide throttleability range over several operating conditions

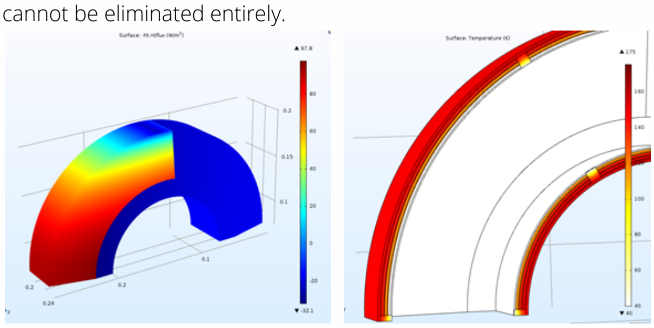
HTS magnets have no heat generation, occupy far less volume and lose all resistance when operated below their critical temperature. However critical temperatures for HTS magnets are usually below 70K. The challenge then comes to maintaining an environment to satiate these conditions.

Thermal Simulation

A heat load will always be directed towards the cryostat from the thermal gradient enforced by the cryogenic system. The methods of attack will be:

- Conduction
  - Scaffolding supporting the cryostat
  - Tie-rods that hold together the various cryostat vessels
- Radiation
  - Internal components
  - Solar environment

While intelligent cryostat design will focus on reducing these, they cannot be eliminated entirely.



Radiation shields are used in the vacuum voids of the cryostat. The number of these shields require a cost-benefit analysis. Too many shields will incur heat loads via conduction, too little will incur a large view factor. This thermal simulation can be used to determine the number of shields.

By using the solar constant we can account for worst-case scenarios from environmental radiation. As subsystem developments will fluctuate, a parametric sweep will account for radiation from internal components.

Currently, tie-rods are modelled as simple cylinders with no clearance. In reality, these would be flanged sex-bolts. A livelinked COMSOL model enables a method of analysing various tie-rods.

This simulation does not model the cooling mechanism. The internal shell is a fixed temperature domain.

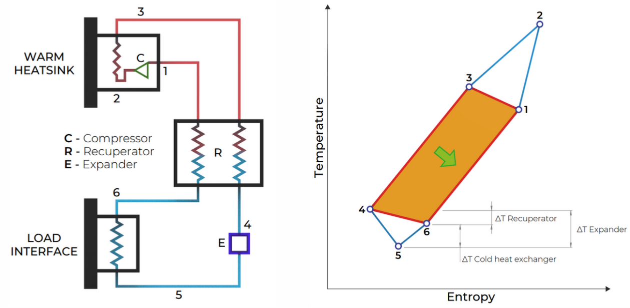
Feroz T Khan
+44 7428 181349
feroz.k@neutronstar.systems

CITY UNIVERSITY OF LONDON — EST 1894

UK SPACE AGENCY

Cryogenics

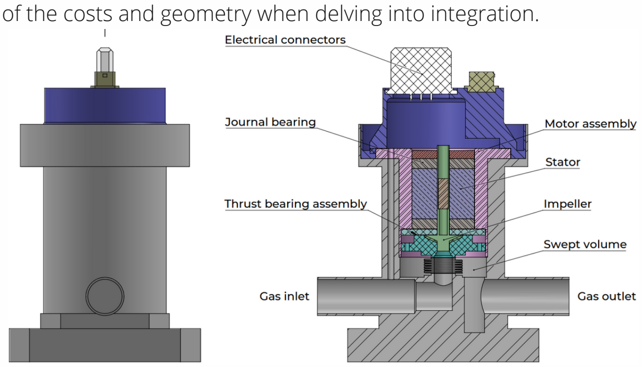
Cryogenics is the science of ultra low-temperature generation. In space, cryogenics is mostly used for cooling instrumentation and propellants onboard. The devices used to achieve such cooling requirements at low temperatures are termed *cryocoolers*. A cryocooler in space demands specific characteristics such as high reliability, low maintenance and vibration-free operation.



Based on the available technologies and the specific application of NSS needs, a miniature *Reverse-Turbo-Brayton Cooler* (RTBC) was selected. To evaluate the performance of the system a thermal model was developed in MATLAB.

This thermal model calculates the enthalpy at each state point within the RTBC. As the pressures of the RTBC are unknown, a 2D matrix was arranged allowing for an optimisation code to select the best pressures while maximising the Coefficient of Performance (COP). This thermal model accounts for irreversibility and losses where possible, using literature as a guideline. While also leaving these inputs as simple parameters, easy to vary in the future as more information unveils.

Based on the estimated cooling power required, the model outputs the total power consumption by the compressors and expander, the COP, the Exergy efficiency and the volumetric flow rate of each compression stage. These key parameters can be used for selecting components allowing for a better understanding of the costs and geometry when delving into integration.



The required cooling power is being estimated in each iteration of the thermal model. To properly assess power consumption needs for each power class of SUPREME it is important to understand the nature of this required cooling power as it will necessitate the design requirements of the cryocooler.

Future Work

Currently, the internal vessel is defined as a fixed temperature, assuming an incredible effectiveness of the cryogenic system. It is essential to consider convective heat transfer for the fluid and shell.

Following some key integrations, the geometry of the mechanical interface between the cryocooler and the cryostat is paramount. Furthermore, the simulation should include the insulation barriers from the thermal management subsystem as well as the scaffolding structure holding the cryostat.