Thermal optimization in srf cryomodule production

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ABSTRACT

Superconducting Radio Frequency (SRF) cavities are becoming the preferred method of particle acceleration for many new high energy physics projects around the world. These SRF cavities are assembled, in series, into a thermal structure known as a cryomodule (CM). Currently, Thomas Jefferson National Accelerator Facility (JLab) is providing the superconducting cryomodules for both the Spallation Neutron Source (SNS) and the prototype for the energy upgrade to the JLab Continuous Electron Beam Accelerator Facility (CEBAF). Once completed, the cryomodules are assembled in series to form a superconducting linear accelerator (LINAC) utilized primarily for particle physics research and development. During operation, the cryomodule maintains the temperature of the cavities at 2K, while the external shell of the cryomodule is at ambient temperature (293K). This paper will present the design, fabrication and assembly of the CM components in order to optimize thermal performance, which is vital to the SRF cavity operation. This thermal optimization will include both static & dynamic heat load considerations as well as design and assembly techniques.

INTRODUCTION

Cryomodules are designed to act as thermal insulators for the superconducting niobium cavities [1][3] with a temperature gradient of about 300K. These superconducting cavities operate at 2K (nominal) and are the driving force behind particle acceleration. Maintaining the operational temperature is critical to the function of the cavities, due to the power dissipation requirements, as it pertains to the superconducting properties of the niobium material. Changes in the operating temperature by as much as a few tenths of a degree K have proven to have adverse effects on both the operating pressure and power dissipation. To sustain these thermal operational conditions, two cryogenic cooling circuits

are built into the structure of the cryomodule. The first circuit (or primary circuit) is the liquid helium bath that surrounds the cavities and operates at 2.1K and .040 atm. This circuit includes the cavities, helium vessels and some beamline components such as the field probes (FP) and higher order mode (HOM) couplers. The second circuit (or secondary circuit) is the copper shield cooled by helium gas and operates nominally at 50K and 4 atm. The design and fabrication of these cryogenic circuits will be presented along with other thermal considerations associated with the fabrication and operation of the cryomodules such as instrumentation and support structure.

PRIMARY COOLING CIRCUIT

The cryomodule starts with the assembly of the cavity string in a class 100 cleanroom (FIG 1) in order to ensure no particulates (contaminants) get into the niobium cavities. Any contamination in the cavities can significantly degrade their performance and in turn their ability to function properly. Once the cavities are assembled, isolation valves are installed, the internal space is evacuated and leak checked. Upon completion, the cavity string is then transferred to the cryomodule assembly area to carry out the remaining assembly tasks.

FIGURE 1. Cavity String in Cleanroom

FIGURE 2. MLI Installed onto Helium Vessel Heads

The first step (with respect to thermal considerations) in the assembly process is to install twelve layers of MLI (multi layer insulation) onto the head surface of each of the helium vessels (FIG 2). This is a precautionary task in the event of an upset condition such as loss of insulating vacuum. In this scenario, the MLI on the surface of the helium vessel would aid in the impedance of heat transfer to the helium bath, which in turn lessens the boil off and rate of increase in pressure.

Magnetic shielding is installed around the cavity string in order to minimize the effect of the earth's magnetic fields on the operation of the cavities. The 2K MLI, consisting of fifteen layers, is then installed over the magnetic shielding, enclosing the cavity string to form the cold mass portion of the cryomodule. Additionally, the beamline instrumentation cables (FP & HOM) are thermally 'stationed' to the cold mass structure in order to limit the heat load directly on the cavity as well as ensuring proper function and signal read back.

Each cavity operates at a specified frequency, which is maintained by a tuning mechanism. This tuning assembly is directly mounted to the cavity and must be thermally consistent with the cavity in order not to degrade cavity performance (FIG 3). In order to increase the cooldown rate, the tuner is thermally anchored to the helium vessel. This

thermal strap also helps improve the thermal profile of the tuner assembly. The tuner assembly consists of an electric motor and a piezo. The heat load to the cold mass from these two components has been tested and measured to be minimal under normal operating conditions.

FIGURE 3. Cavity String Assembly

FIGURE 4. Integral Spaceframe & Thermal shield

SECONDARY COOLING CIRCUIT

Once the cold mass is complete, the 50K nominal thermal shield prepared and installed. The copper thermal shield is integrated into the spaceframe support structure (FIG 4). The spaceframe is the support structure for the cavity string inside of the vacuum vessel and is nominally at a temperature of 300K. In order to thermally isolate the copper shield from the spaceframe, G10 posts and brackets are utilized as a support structure for the 50K shield with respect to the spaceframe. The thermal properties of the G10 and the long thermal path successfully isolate the 50K and 300K structures.

As previously stated, the spaceframe is the support structure for the cavity string via high strength stainless steel rods referred to as nitronic rods. These rods are attached to the 2K helium vessels at one end, and to the 300K spaceframe at the opposite end. In order to limit the heat load to the 2K circuit and in turn on the refrigeration system [2], the nitronic rods are thermally anchored to the 50K nominal thermal shield (FIG 6). Sixty layers of MLI are installed around the thermal shield to insulate it from the 300K spaceframe and vacuum vessel.

FIGURE 5. G10 Thermal Shield Support

FIGURE 6. Nitronic Rod Thermal Station Strap

As with the 2K circuit, the beamline instrumentation is ‘stationed’ again at the 50K shield, along its path out to the vacuum vessel feedthru plate. This technique aids in the

heat load distribution of the cables from their origin at the beamline (2K) up and out to their destination at the 300K vacuum vessel.

END CANS & INSULATING VACUUM

The completed spaceframe and thermal shield assembly is inserted into the vacuum vessel and the end cans are then installed to cap each end of the cryomodule (FIG 7). These final components form the completion of the 50K thermal shield along with the insulating vacuum space to complete the assembly of the cryomodule (FIG 8). Both the end cans (supply & return) facilitate the flow of cryogens through the cryomodule for both the 2K and 50K cooling circuits.

Leak checking the cryogenic circuit is one of the most important parts of the cryomodule assembly process. All cryogenic circuits are cold shocked with liquid nitrogen and leak checked with a helium mass spectrometer calibrated to a minimum detectable leak (MDL) of 2×10^{-10} torr-liter/second or smaller.

FIGURE 7. Cold Mass inserted into Vacuum Vessel

FIGURE 8. Completed cryomodule ready for testing

CONCLUSION

Cryomodule design and fabrication technology has developed over the years into a very reliable entity to accommodate particle acceleration. This technology continues to evolve with the advent of new nuclear physics requirements as well as the potential for industrial applications. The uniting of cryogenic and accelerator engineering has created a technology development practice, that will bring forth, many new physics discoveries, new thermal operational techniques, as well as expand these engineering fields of research.

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