C2Po1E-06 Helium Flow Meter for Measuring SRF Cavity Power Dissipation *§

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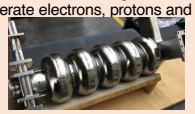
Abstract

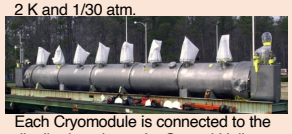
We present a helium gas flow meter, acting as a power meter that measures 3 to 7 K helium vapor evaporating from a superfluid, 2 K helium bath at 1/30 Atm. The meter is proven to work in gas velocities of 1 to 14 m/s and resolves helium evaporation to 0.05 g/s (1 W) or less. In the Thomas Jefferson National Accelerator Facility (JLab) application, the Instrument Head is installed in the return U-tube of an 8 Cavity, Superconducting Radio Frequency (SRF) Cryomodule (Horizontal Dewar). The Meter measures power dissipation in the 30 W range from individual SRF Cavities at different operating gradients. The goal of the measurement is to identify contaminated cavities with excess power dissipation. In addition, the Meter can measure the total heat dissipation of the entire Cryomodule in the 200 W with beam on. The meter's great sensitivity, in this unusual temperature and pressure range, is the huge signal change from a superconducting niobium-titanium sensor element (Tc=9.2K) going normal. It is adjacent to a resistive heater. The cooling from ~3K helium vapor is bucked against resistive heat until the sensor's temperature rises to a fractionally normal-conducting state. In the hot wire anemometer mode, the heater current is continuously adjusted to maintain a constant, fractionally normal (say 50%) sensor state. This mode is more sensitive than stated above, even seeing the small variations in the Central Helium Liquefier's (CHL) supply parameters. The second, "sawtooth" operational mode straddles the above cryogenic variations by cyclically varying the heater current until a fractional normal state is detected and then decreasing current for another cycle. In this mode, the meter's "Reading" is the average of the sawtoothed, maximum heater current readings over multiple cycles. Since the meter's reading is sensitive to the gas temperature, each flow meter reading is contemporaneously calibrated with the cavity off with a matched reading created by power from the Cryomodule's built-in heaters. N electronics Chassis services the Meter based on a printed circuit board interface to a AtoD, DtoA LabJack T7. A Linux-based control system is an integral part of this device, providing the necessary control and data processing capabilities. The Flow Meter is a rapid and reliable method for assessing cavity performance vs. accelerating gradient, expediting commissioning processes. At JLab, it replaced the cumbersome and time-consuming method originally used in qualifying LCLS-II-HE Cryomodules. It is installed in 19 of 52 positions in CEBAF and its use and data are being integrated into Operations. It allows cavity dissipation tracking over time, optimizing SRF systems' efficiency, guiding cryogenic heat load management, and enhancing the correlation of eventual cavity performance degradation with possible environmental or hardware-related influences.

Background:

- Superconducting Radio Frequency (SRF) Cavities are used in large accelerators to accelerate electrons, protons and ions.



- They operate at 2 to 4 K, cooled by liquid helium.
- Jefferson Lab's (JLab) CEBAF (Continuous Electron Beam Acceleration Facility) uses 53 Cryostats called Cryomodules, each housing eight, ~0.5 m long SRF cavities, operating at 2 K and 1/30 atm.



- Each Cryomodule is connected to the distribution pipes of a Central Helium Liquefier's (CHL) via "U-Tubes".
- SRF Cavities work using pumped-in Microwave Power (1.5 GHz at JLab).
- The SRF cavities **have to be super clean**, otherwise, they act like a microwave oven **heating** any contaminating dust particles.
- Contamination causes excess helium boil-off.
- Field emission from particles causes excess radiation in the vault.

The NEED, the Motivation and Objectives:

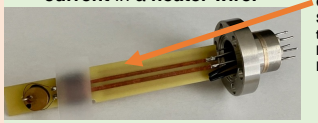
- For 37 Years, Operators of CEBAF needed a **non-invasive, in-situ** way of finding the individual cavities that generated excess power and thus boiled excess helium.
- They need the data in **Watts** – 23 Watts boil 1 gm per second from a 2K bath – **so an accurate FLOW METER would work!**

The Solution:

- Responding to a 2022 DOE SBIR Topic, Hyperboloid LLC, using a cooperative research agreement with JLab, developed a Helium Flowmeter that has Watt level resolution.
- Located in the 1/30 atm, 3-K return gas U-Tube.

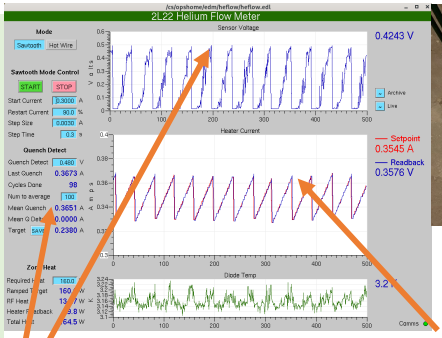
How the Instrument Head works

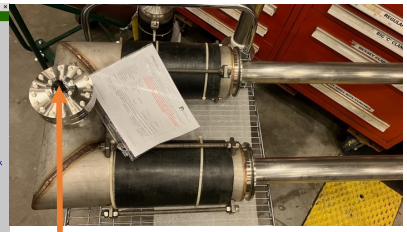
- During a down time, a single SRF Cavity is run at a selected "gradient" (accelerating power), evaporating helium.
- **At the Instrument Head**, The ***cooling*** from **helium flow** back to the CHL through the U-Tube is bucked against the ***heat*** from a **rising current** in a **heater wire.**



G-11 Blade Supporting the Instrument Head

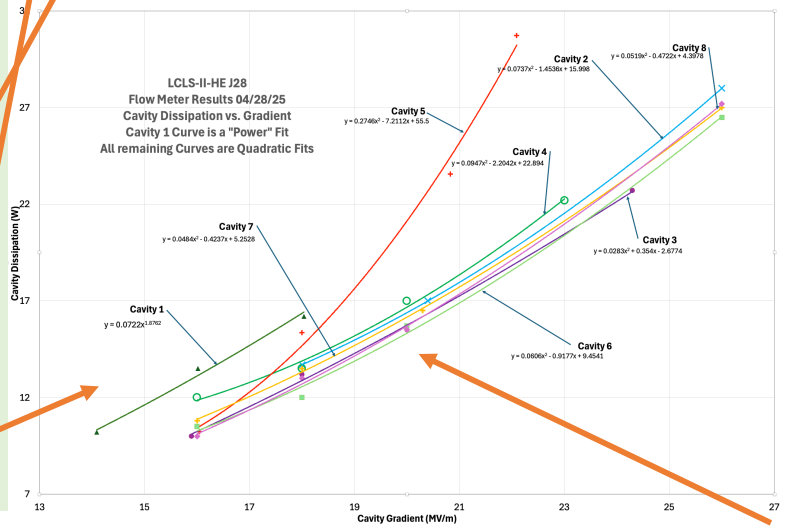
- Sandwiched between the Heater Wire is a Superconductor (SC).
- The SC snaps to a **large resistance signal** when its temperature reaches "normal" conducting (T_c ~ 9 K).
- The maximum **heater wire currents**, when "Normal" SC are detected are **averaged** by the EPICS Control System over several heating cycles and displayed on the Screen as **Mean Quench Current (MQC)**.
- Calibration of the MQC to Dissipated Power (Watts) is done immediately.
  - ➢ Turn off the Cavity
  - ➢ Turn on built-in Cryomodule Resistance Heaters
  - ➢ Hunt for and find the **power** that duplicates the MQC.
- **Resolutions to 2 W are seen.**





CEBAF Cryomodule Return Gas U-Tube with Retrofitted Flowmeter installed

Typical Maximum Current in Heater Wire at Quench



LCLS-II-HE Cryomodule Tests use the Flowmeter exclusively to calculate Q0s from Dissipation Data

The Installations to date:

- Fourteen successful Flowmeters installed in CEBAF.
- Two Flowmeters installed in the Cryomodule Test Facility (CMTF) U-Tubes in the Test Lab.
- One Flowmeter installed in the transfer line in the UITF in the Test Lab for testing at 4.5 K.
- Two redundant Flowmeters installed in the Transfer Line for the LCLS-II-HE Cryomodule tests in the Low Energy Research Facility (LERF).
- One Flowmeter installed in the Oak Ridge National Lab, SNS Cryomodule Test Facility.

Future Work and Research

- Characterize Total Dissipation of each Cryomodule while CEBAF is running beam.
- Flowmeter has proven range to 150 W.
- Probably uses a Calibration Curve of Power vs. MQC, augmented with helium temperature correction.
- Characterize response to helium vapor at 4.5 K.
- **Establish a CRADA with another SRF Laboratory to install one Flowmeter.**

The Electronics Chassis, designed by Kevin Jordan at JLab:

- Lab Jack T7 (DtoA, AtoD) interface to EPICS.
- Chassis is two channel, 2U.
- Temperature diode reading included.
- SC Quench detection voltage is 50 to 500 mV.
- All cabling is twisted pair.

CONCLUSION

This Flowmeter is a **proven instrument** to resolve helium evaporation at "WATT" Levels from 10 to 150 Watts (0.4 to 6.5 g/s) at 3 K and 1/30 atm at velocities of 1 to 14 m/s. SRF Accelerator operators need this instrument to characterize the health of their SRF Cavities insitu.

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