

SNS MEDIUM-BETA CRYOMODULE PERFORMANCE*

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Abstract

Thomas Jefferson National Accelerating Facility (Jefferson Lab) is producing 24 Superconducting Radio Frequency (SRF) cryomodules for the Spallation Neutron Source (SNS) cold linac. This includes one medium-beta (0.61) prototype, 11 medium-beta production, and 12 high-beta (0.81) production cryomodules. Each of the medium-beta cryomodules is scheduled to undergo complete operational performance testing at Jefferson Laboratory before shipment to ORNL. To date, the prototype and three production models of the medium-beta cryomodule have been tested. The performance results of the tested production cryomodules will be discussed.

INTRODUCTION

Jefferson Lab has completed construction of six medium-beta cryomodules, and testing is currently underway in the recently upgraded Cryomodule Test Facility (CMTF) [1].

While installed in the CMTF, each cryomodule will be subjected to a series of performance tests based on SNS specifications.

The testing process begins once the cryomodule has been cooled to 2K. Table 1 has a list of tests performed as a part of the production testing process.

Table 1: List of Production Tests

Test or Procedure	Purpose
Tuner Range, Hysteresis	Determine proper operation of piezo and mechanical tuners.
Tuner Resolution	Determine frequency resolution of piezo and mechanical tuners.
High Power Processing	Condition Coupler Vacuum, Determine E_{max} .
Extended Run	Determine Maximum Stable Gradient, E_{maxop} .
Field Emission	Measure Field Emission vs. Gradient.
Q_{ext} 's	Measure Q_{ext} 's of Fundamental Power Coupler, Field Probe and Higher Order Mode Couplers.
Q_0	Measure Q_0 vs. Gradient.
Lorentz Force Pulse Response	Measure Dynamic Lorentz Force Coefficient

Other measurements may be added as needed. The high power production tests require the use of a 1 MW pulsed klystron. Other tests, such as tuner tests are

performed using a low power (1 W) setup. To date, the prototype and three production models of the medium-beta cryomodule have been tested. The performance results of the tested production cryomodules will be discussed.

TUNERS

The SNS tuner design has been adapted from a Saclay tuner design for the TESLA cavities. For SNS application, the tuner requirements are listed in table 1. In order to meet the SNS requirements a piezo element has been incorporated into the “dead leg” and provides the required fine tuning adjustment [2].

Mechanical Tuner Tests

The mechanical tuners are tested to determine frequency range, hysteresis and resolution. The tuner is cycled through its range from the clockwise limit switch to the counter-clockwise limit switch. This is done in steps of ~ 25 kHz (60000 half-steps of the stepper motor). The tuner is then cycled through a smaller, 4 kHz loop using increments of 600 half-steps (~ 200 Hz) for determination of hysteresis. See Figure 1 for a typical plot of frequency vs. motor position.

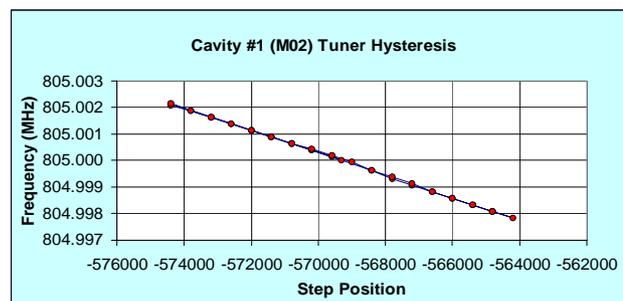


Figure 1: Mechanical Tuner Range and Hysteresis.

The SNS requirement for the mechanical tuner range is 200 kHz ($805 \text{ MHz} \pm 100 \text{ kHz}$). The average range for cryomodules M1-M3 is $486 \text{ kHz} \pm 28 \text{ kHz}$. The average hysteresis for this group of cavities is $90 \text{ Hz} \pm 33 \text{ Hz}$.

In order to determine the resolution of the mechanical tuner, the stepper motor is cycled back and forth by a set number of steps while using a cavity resonance monitor (CRM) to look at the signal from the cavity field probe. A VCO-PLL system and a 1 W amplifier are used to drive the cavity. The number of motor steps is reduced until the frequency shift measured by the CRM is less than 60 Hz

(based on the SNS requirement). Figure 2 shows the result of a typical test.

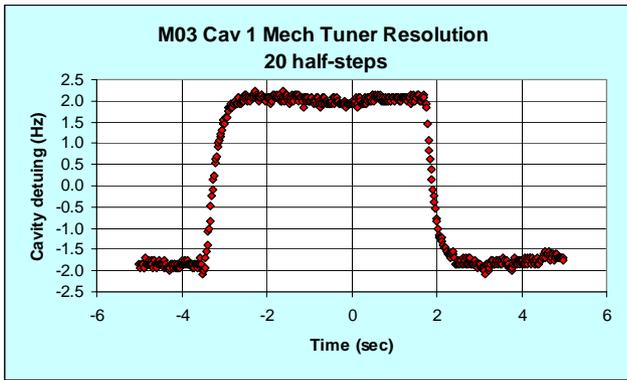


Figure 2: Mechanical tuner Resolution.

The average measured resolution for the tested cavities is $9.9 \text{ Hz} \pm 8.9 \text{ Hz}$.

Piezo Tuners

The same types of tests are performed on the piezo tuners: range, hysteresis and resolution.

During the range and hysteresis tests, the piezo drive voltage is increased from zero to 850 Volts in steps of 100 Volts ($\sim 250 \text{ Hz}$), and then decreased in the same fashion to zero Volts. A typical plot is shown in Figure 3.

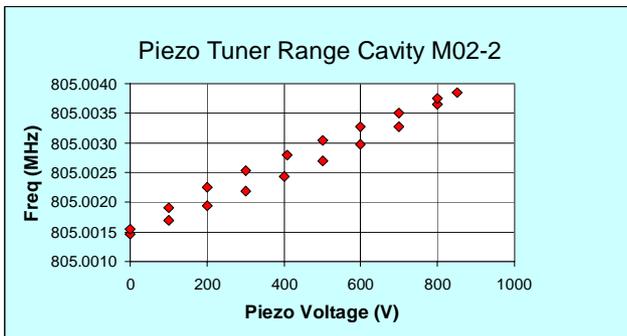


Figure 3: Piezo Range and Hysteresis.

The average measured frequency range for the piezo tuners is $2.9 \text{ kHz} \pm 0.4 \text{ kHz}$. The average hysteresis is $643 \text{ Hz} \pm 349 \text{ Hz}$.

Finally, we measure the piezo tuner's resolution. A pulse generator is used to drive the piezo tuner with a 0.2 Hz, 50 % duty cycle pulse train. The cavity under test is driven with a VCO-PLL and a 1 W amplifier. The CRM is used to measure the frequency shift. The amplitude of the pulse train is set initially at 0.05 V and reduced until the measured frequency change is less than 60 Hz (peak to peak). Figure 4 shows the result of a typical test.

HIGH POWER MEASUREMENTS

During high power measurements, a 1 MW klystron is connected to the cavity under test. It is set up to deliver a 1.2 ms pulse with a 60 Hz repetition rate.

The first task is to process the coupler vacuum and define the maximum gradient (E_{max}).

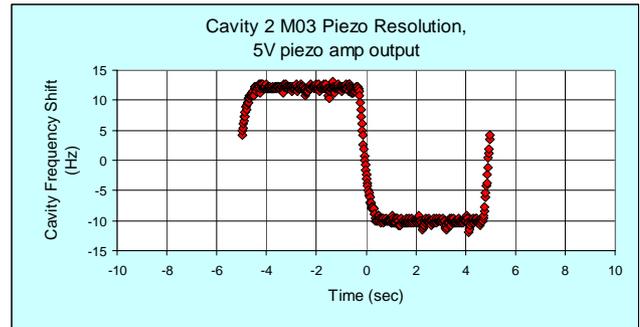


Figure 4: Piezo Tuner Resolution.

This is accomplished by gradually raising the gradient while allowing time for the coupler vacuum to improve. Eventually, the gradient is raised to a level that cannot be sustained due to cavity quenches or an interlock fault is triggered and the RF permit is removed. This condition occurs as a result of arcing or vacuum degradation. Figure 5 shows the progress over time as the gradient is raised over a nine-hour period. It depicts the slow increase in gradient and the behavior of the coupler vacuum. It is a fairly typical session, although the times required vary from as little as four hours to several days.

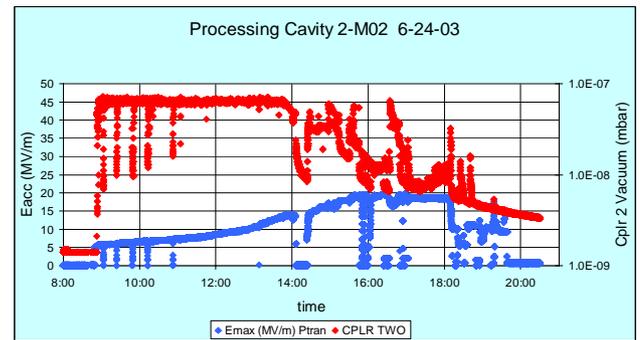


Figure 5: Processing Session.

Once E_{max} has been determined, we look for the maximum *stable* gradient (E_{maxop}). We lower the gradient by about 1 MV/m in order to avoid unstable conditions such as quenches. The cavity must operate at E_{maxop} in a stable fashion for at least an hour.

Table 2: E_{max} for Measured Cavities

SNS Requirement	$\geq 10.1 \text{ MV/m}$
Average for E_{max}	$18.8 \text{ MV/m} \pm 1 \text{ MV/m}$
Average for E_{maxop}	$17.4 \text{ MV/m} \pm 1.4 \text{ MV/m}$

After processing has been completed and the maximum gradient has been defined, it is time to measure the unloaded Q (Q_0).

A calorimetric method is used. The cryomodule under test is isolated from the cryogenic system by closing the

helium input and output valves. The rate of change in pressure ($\Delta P/\Delta t$) as a result of the 1) static heat load, 2) the static heat load plus a known input from a cryogenic heater and 3) the static heat load plus the RF heat load. From these measurements we are able to determine both Q_0 (and the primary (2 K) static heat load). Figure 6 shows the results of Q_0 measurements on the first three production cryomodules.

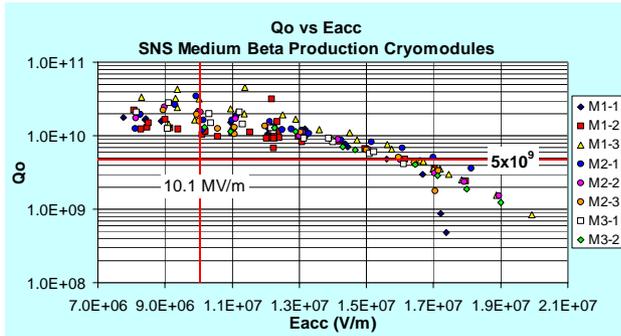


Figure 6: Q_0 vs. E_{acc}

Table 3 summarizes the results. The SNS requirement is $Q_0 \geq 5 \times 10^9$ at $E_{acc} = 10.1$ MV/m. The static heat load requirement is 25 Watts or less.

Table 3 Average Q_0 Values

Q_0 at 10.1 MV/m	$1.4 \times 10^{10} \pm 1.9 \times 10^9$
E_{acc} at 5×10^9	15.6 MV/m ± 1.1 MV/m
Static Heat Load	10.5 W ± 1.1 W

At this time, we also look at field emission. A set of five Geiger-Mueller (GM) tubes is placed around the cryomodule and the response at different gradient levels is recorded. Figure 7 shows the response of the GM tube located at the beamline on the helium supply end of the first three production cryomodules. This is the location where the highest level of field emission has been recorded so far.

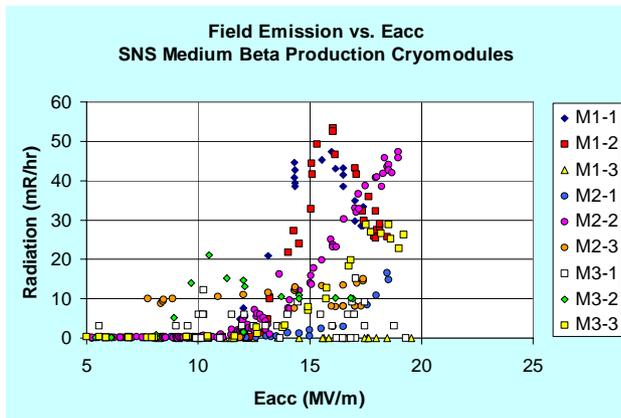


Figure 7: Field Emission.

The average gradient at which field emission starts for these cavities is 10.3 MV/m ± 2.8 MV/m.

The Q_0 measurements are followed by the dynamic Lorentz force measurement, which measures the frequency response of the cavity to an RF pulse. Figure 89 shows the frequency shift to an RF pulse for a typical cavity operating at 10 MV/m.

The average frequency shift for the medium-beta production cavities tested so far is 283 Hz ± 29 Hz.

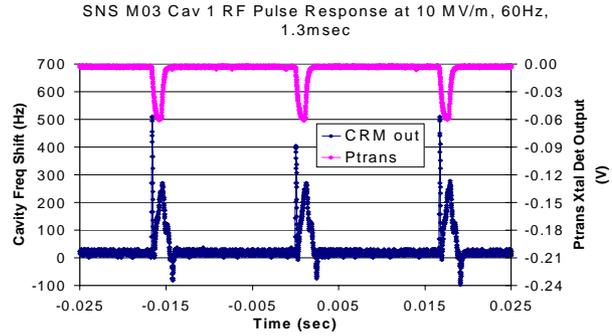


Figure 8: Frequency Response to Pulsed RF.

Finally, as part of the high power measurements, the external Q 's (Q_{ext}) of the FPC, the field probes and the HOM ports are measured. Table 3 summarizes the results of those measurements.

Table 4: Q_{ext}

	SNS requirement	Measured value
Q_{ext} FPC	$7.3 \times 10^5 \pm 20\%$	$7.1 \times 10^5 \pm 13\%$
Q_{ext} field probe	$1.052 \times 10^{12} \leq Q_{ext} \leq 2.642 \times 10^{12}$	$1.9 \times 10^{12} \pm 6.5 \times 10^{11}$
Q_{ext} HOM1	$> 3 \times 10^{10}$	$1.2 \times 10^{14} \pm 1.9 \times 10^{14}$
Q_{ext} HOM2	$> 3 \times 10^{10}$	$1.9 \times 10^{10} \pm 9.1 \times 10^{11}$

So far, two of the cavities tested have failed to meet the requirement for the HOM 2 port.

CONCLUSION

The first three production models of the SNS medium-beta cryomodule have completed testing. The three cryomodules have exceeded all requirements other than the two exceptions noted above.

REFERENCES

- [1] Powers, T. Allison, G. K. Davis, M. Drury, C. Grenoble, L. King, T. Plawski, and J. Preble, "Upgrade To Cryomodule Test Facility at Jefferson Lab", SRF Workshop 2003
- [2] J. Preble, I. E. Campisi, E. Daly, G. K. Davis, J. R. Delayen, M. Drury, C. Grenoble, J. Hogan, L. King, P. Kneisel, J. Mammosser, T. Powers, M. Stirbet, H. Wang, T. Whitlatch, M. Wiseman, "SNS Cryomodule Performance", PAC 2003