BNL 703 MHZ SUPERCONDUCTING RF CAVITY TESTING

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Abstract

The BNL 5-cell, 703 MHz superconducting accelerating cavity has been installed in the high-current ERL experiment. This experiment will function as a proving ground for the development of high-current machines in general and is particularly targeted at beam development for an electron-ion collider (eRHIC). The cavity performed well in vertical tests, demonstrating gradients of 20 MV/m and a Q_0 of 1e10. Here we will present its performance in the horizontal tests, and discuss technical issues involved in its implementation in the ERL.

INTRODUCTION

The BNL 5-cell 703 MHz superconducting accelerating cavity is a critical component in the development of a high average current ERL prototype at Brookhaven National Laboratory. The cavity has been designed and developed in collaboration with Advanced Energy Systems of Medford, New York. The bare cavity was tested in the vertical test area (VTA) of Jefferson Laboratory, where the design gradient of 20 MV/m was achieved, with a Q_0 exceeding 10^{10}, at an operating temperature of 2K [1]. Preliminary testing of the cavity in the hermetic string assembly using pulsed fields also demonstrated operation at the design gradient [2].

Subsequent cold tests have uncovered a thermal problem which prevents CW operation of the cavity at gradients above 12 MV/m, which we discuss in the first section below. We consider then the potential for conducting the prototype experiments in a “quasi-cw” mode in the following section. Finally we consider the impact of mechanical noise on cavity operation.

CW OPERATION AND THERMAL ISSUES

Niobium beampipes extend from both ends of the cavity, for lengths of 19 cm on the side on which the tuner is located and 25 cm on the side containing the fundamental power coupler. The beampipes terminate in NbTi flanges, which are sealed with $AlMg_3$ hexagonal seals to copper plated stainless steel flanges. Beyond the stainless steel flanges are thermal transition regions, which are cooled by independent 5K Helium circuits. Fig. 1 shows the arrangement schematically, on one side of the cavity only. .The primary cooling for the beampipes is thus by conduction to the 2K bath that cools the cavity, with the 5K circuits minimizing the heat load from the transition region.

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Dept. of Energy
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The CW operation problem was initially masked by a multipacting resonance observed just below the 12 MV/m threshold during the first cold tests[2]. In subsequent tests however, elevated temperatures were observed on the outer edges of the flanges at the end of the beampipes (T_t=11K and T_{fpc}=7K on the tuner and FPC ends respectively). These temperatures increased with increasing operating gradient, until the cavity quenched at a gradient of ~12 MV/m, when flange temperatures T_t and T_{fpc} surpassed 25K and 15K respectively.

A series of thermal tests revealed conductive heat leaks from the magnetic shield and tuner to the transition regions just beyond the beampipe terminations. It was thought that, since T_t exceeded the superconducting critical temperature for NbTi, a portion of the inner flange exposed to RF fields could be normal conducting, and that resistive heating would then drive the temperature higher, extending the normal conducting region into higher field regions where heating would again increase, causing a “thermal runaway” until the cavity quenched.

In order to reduce the heat leaks, the tuner and magnetic shield were cooled over a period of weeks using liquid nitrogen boil-off through the 5K circuits. The tuner and shield are designed to be thermally isolated, so that cooling could only be done through the conductive heat leaks and was quite slow. The leaks were reduced so that the flange temperatures were both well below the critical temperature of NbTi (Tt=7K, Tfpc=6K). However the thermal behavior with increasing gradient remained the same, quenching at the same gradient and temperature values as before, indicating another cause of the thermal runaway.

The source of the problem was determined to be the $AlMg_3$ seal located between the NbTi and stainless steel flanges. We have conducted a 3-dimensional simulation of the resistive heating and thermal transport that confirms this interpretation quantitatively. The simulation is presented elsewhere in these proceedings [3], so we simply summarize its conclusions here. The seal geometry leaves a gap of ~1.25 mm between the NbTi flange and the mating flange, allowing RF fields to penetrate to the seal. On the tuner side, at the point of thermal runaway, the amplitude of the RF magnetic field at the seal is ~200 A/m. This causes dissipation of less than 1W of power in the seal but, due to the poor thermal properties of NbTi , portions of the NbTi flange that also see the RF field heat up, become normal conducting, and generate additional heat. Once the flange raises the temperature of the end of the beampipe above the critical temperature, the thermal runaway rapidly quenches the cavity.

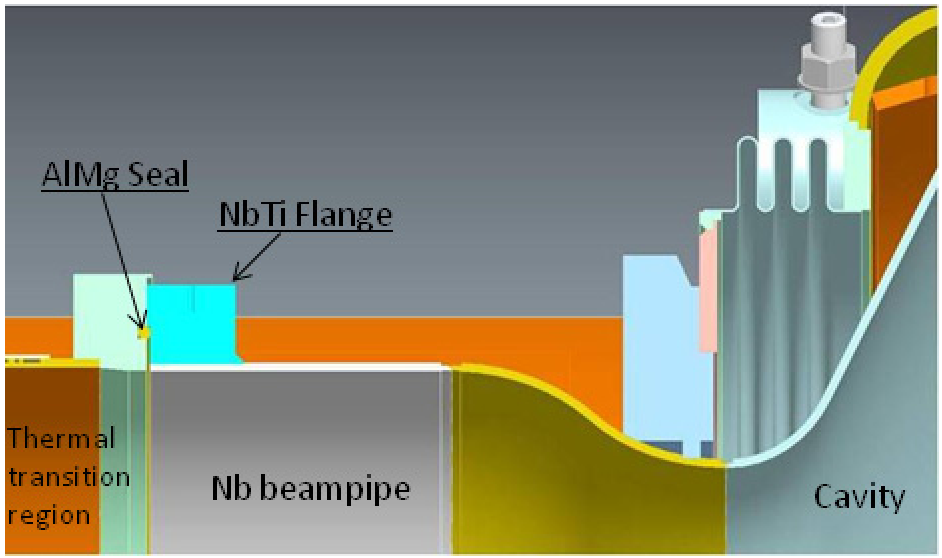

Figure 1: Geometry of the cavity, beampipe and thermal transition region. The AlMg seal mating the NbTi flange to the transition region is the source of the thermal problem.

QUASI-CW OPERATION

Options to provide supplementary cooling to the NbTi flanges were evaluated and found to be inadequate. To remedy the thermal problem, the seal design must be changed or the beampipe extended. While a solution can be implemented in the final cavity design, fixing the prototype cavity would introduce unacceptable delays to the program. At the same time, for use in the ERL prototype, it is necessary to achieve an acceleration of at least 15 MV in the cavity, due to beam-dynamics constraints in the beam combiner.

However, the prototype program can still be pursued if the cavity can be operated in a pulsed "quasi-cw' mode, in which the cavity is on, with stable gradient, for a time long compared with the transit time through the ERL loop (10 nsec). We have thus tested operating the cavity while pulsing the RF, and optimized pulse length and duty cycle for thermal stability, in order to find a regime where the ERL can be run continuously for long enough to evaluate true CW behavior, and yet remain thermally stable over an indefinite period of time.

The results are shown in Fig 2. We find that by adopting a duty cycle of ~1:15 (on:off), we can safely turn the cavity up to an accelerating gradient of 18 MV/m, and still maintain thermal stability, the excess heat created by the above-described mechanism during the on period being dissipated during the off period. We demonstrated continuous running for 30 minutes with a pulse length of 2 seconds, and an off time of 30 seconds. During the "off" phase, the gradient is held at 3 MV/m. The longest pulse achieved before quenching was 5 seconds..

Radiation levels observed are similar to those observed in preliminary tests. Making an approximate correction for the fact that the Chipmunk response time is longer than our pulse length, we estimate a peak rate of 20-30 rem/hr at 1 meter downstream of the cavity. This indicates that some field emission is occurring. Extensive processing of the cavity has not yet been possible, as the cryogenic system is open-loop, and the times and Helium consumption involved are prohibitive. A closed-loop cryogenic system will be operational later this year and should afford progress on this issue.

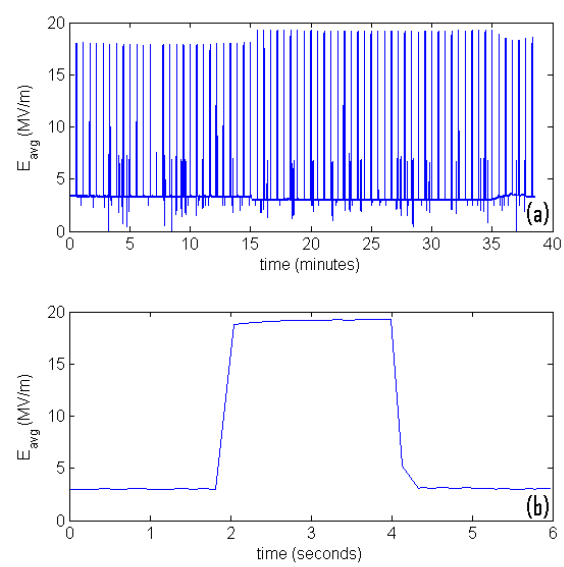

Figure 2: (a) Average accelerating gradient vs. time in the cavity during quasi-cw operation. Pulses are 2 seconds long with a 30 second interval. The intermittent noise between pulses is an instrumental artefact, (b) single pulse expanded.

NOISE MEASUREMENTS

We have conducted some preliminary studies of microphonic noise on the cavity. Microphonics are detected through the error signal on a phase-locked loop that locks the low-level RF (LLRF) frequency to the cavity frequency, which is allowed to vary. The error signal drives a voltage-controlled oscillator (VCO) that shifts the LLRF frequency, closing the loop. The calibration of the VCO then gives the magnitude of the cavity frequency shift in time as a function of the error signal. The noise spectrum is obtained from the Fourier transform of the error signal.

In discussing the noise spectrum a confusion naturally arises between two frequencies: the frequency at which the cavity frequency varies, which we will denote by f, and the magnitude of that variation – i.e. the amplitude of a particular spectral component – which we will denote by M(f).

The low-frequency noise spectrum is shown in Fig 3. The spectrum was taken in CW operation at a gradient of 2 MV/m. We see clear peaks, the strongest at f=16 and f=30 Hz. The amplitude of these two peaks varies over time by several Hz, but the sources have not yet been identified. While the discrete peaks are of only moderate strength, the presence of multiple frequencies could present difficulties with feedback and control in locking the cavity frequency. The instrumental contribution to the broad background is also not yet fully understood. The instrumentation for locking the frequency of the cavity to the reference, rather than vice-versa, is being developed and will be implemented shortly.

A much stronger, resonant effect has also been observed, primarily when the liquid level in the helium vessel is low. A low frequency oscillation in the cavity frequency, with amplitude up to many hundreds of Hz, will be repeatedly excited and ring down in amplitude over a few seconds. The frequency (f) of this resonance is typically 16 Hz but is observed to shift with changing Helium pressure in the cryostat. Some connection with a thermoacoustic oscillation is suspected, because of the close dependence on cryogenic parameters, but the phenomenon is not yet well-understood. Because its occurrence is idiosyncratic, it is hoped that it can eventually be suppressed or avoided.

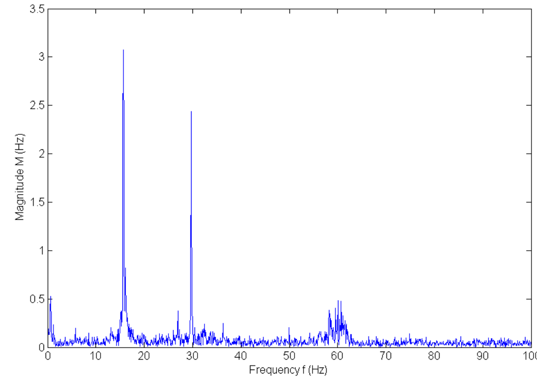

Figure 3: Spectrum of microphonic noise.

SUMMARY

The BNL 703 MHz superconducting cavity has been installed and operational tests are ongoing. A thermal problem has been discovered, which prevents CW operation at gradients above ~12 MV/m. However, a "quasi-cw" operational mode has been identified which will permit the execution of the prototype program. Preliminary studies of the microphonics spectrum reveal some discrete noise sources of moderate strength, and a large resonance which occurs infrequently and is still under investigation.

REFERENCES

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