FERRITE COVERED CERAMIC BREAK HOM DAMPER*

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Abstract
The Brookhaven Energy Recovery Linac is operated as R&D test bed for high-current, high-charge electron beams. It comprises a superconducting five-cell cavity and a half-cell SC photo injector electron RF gun. Achieving the performance objectives requires effective HOM damping in the linac and gun cavity. This paper presents a novel beam-tube HOM damper for the gun cavity consisting of a ferrite covered ceramic break. The superconducting Q measurements remain to be measured. In the interim, the ferrite damping properties are numerically analyzed in terms of radial waveguide modes.

INTRODUCTION

The Ampere class 20 MeV superconducting Energy Recovery Linac (ERL) is presently under commissioning at the Brookhaven National Laboratory (BNL). This facility enables testing of concepts relevant for envisioned future projects in line with the mission of the laboratory. The ER consists of a superconducting five-cell accelerator cavity [1] plus a photo injector in form of a superconducting half-cell RF cavity [2]. The ERL is designed to operate at 703.75 MHz with high-charge, ~0.7 nC bunches in the 500 mA current at 2 MeV from the gun, and 20 MeV after the accelerator. The Ferrite covered ceramic Break (FB) here studied is installed in the beam line directly at the vacuum gauge of the gun cavity cryostat as shown in Fig. 1. The gun is a half-cell cavity and must be powered by a 1 MW klystron in order to reach the high current design performance. For this the cavity is powered by a dual feed fundamental power coupler (FPC). Testing of the SRF gun cavity in the VTF started in 2010 and was continued in the ERL reaching 2.2 MV in CW mode when powered by a 1 MW klystron[3].

The ERL provides a test bed for the investigation of transverse and longitudinal instabilities caused by Higher Order Modes (HOM) in the superconducting cavities. Required high-current, high-charge operating parameters in the ERL make effective HOM damping mandatory. The primary concern is beam breakup in the recirculated beam by dipoles modes in the accelerator cavity. HOM damping in the accelerator cavity had been demonstrated in the copper cavity model and is achieved at room temperature and in the superconducting ERL cavity [4]. The HOMs in the accelerator cavity are absorbed with a room temperature beam line ferrite damper, following the techniques developed at Cornell and KEKB.

Perceived difficulties with the ferrite tiles when HOM heated lead to the search for alternate dampers for the gun cavity [5]. One of them, the FB for the SC electron gun is the focus of the present paper. The insertion of an aluminum oxide break provides separation of the ferrite bricks from the gun vacuum ensuring the high vacuum and absence of particulates reaching the niobium surface. Details of the FB design and its preparation for installation at the cavity are presented in the next section.

The primary function of the FB is damping of the gun HOMs. A limited number of resonance measurements at ~2 K have been performed on the gun cavity proper during vertical tests and after its installation at the ERL. Additional results were obtained from a second half cell cavity of identical geometry but fabricated from large-grain (LG) niobium. All data for the lowest TM_{01} and TE_{11} like modes are presented in the third Section.

The damper properties are best described by the external Qs that constrain the unloaded mode Q_0's. However, the Q-external depends strongly on the damper location and the cut off frequencies of the beam tube, so that transportable values have not been generated. Portable damper properties, however are best described in terms of impedances at the gap in the beam tube. To compare with beam line dampers, a surface impedance is derived from field analysis in the last section.. The paper is concluded with a short evaluation of the of FB merits.

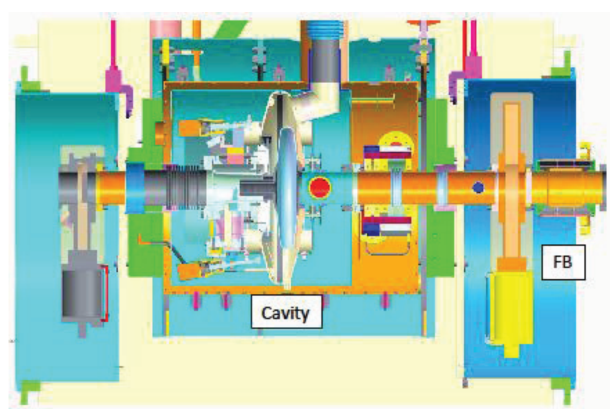

Figure 1: Ferrite break with gun cavity cryostat

FERRITE BREAK DAMPER

The ceramic break underlying the FB, intended to be lossless, is achieved with an aluminum oxide tube (92% Alumina) terminated with stainless steel cuffs and essentially all damping is due to the ferrite. The FB as shown in Fig. 2 has been assembled from surplus ferrite

*Work supported by Brookhaven Science Associates, LLC under contract no. DE-AC02-98CH10886 with the DOE.
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originally procured for the accelerator cavity. The production ERL HOM absorber was obtained from ACCEL Instruments using the nickel-zinc ferrite C-48 tiles produced by Countis Industries. Three ferrite tiles each of 5.08 × 3.81 × 3.18 mm dimensions are soldered to 10W3 Elkonite plates. The unit has room for 12 plates forming a cylindrical 16 cm i.d. ferrite spool over the 10 cm diameter ceramic tube. The plates are placed on the ceramic tube cuff links with metallic clamshell holders. RF leakage between the ferrite plates is prevented by narrow metal stripes.

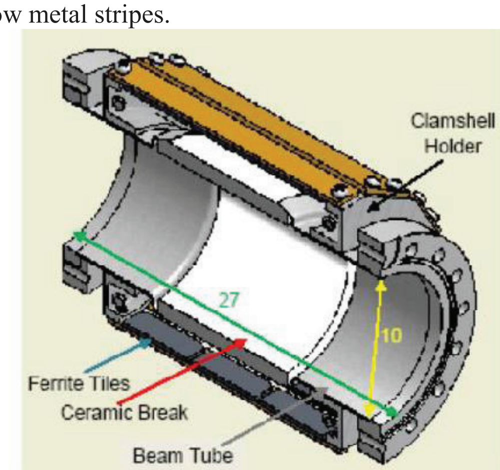

Figure 2: Ferrite plates over ceramic break (in cm)

In normal operation of the ERL cavity, the absorber is at room temperature but can be water cooled through tubes soldered to the plates. Changing the radial size of the holder remains an option to simplify cooling requirements.

The spatial separation of the FB damper from the gun in the cryomodule allows baking of the niobium cavity to improve Q-slope performance if necessary, and alternatively also baking of the damper together with the beam tube to reach high beam tube vacuum.

Ultra-high and dust-free vacuum is essential in the vicinity of the superconducting cavities to maintain highly stable CW gun operation. Preventing electron charge accumulation on the ceramic mandates a ceramic coating with Non-Evaporable Getter (NEG) films. Producing a film as thin as possible to allow HOM power to be transmitted represents a challenge. The goal for the coating was set at a thickness from 45 to 90 Å together with a DC impedance above ~ 100 kΩ. The ceramic vacuum break was coated with Type 321 stainless using magnetron sputtering as coating method.

Maintaining electrical resistivity of the coating, when exposed to atmospheric oxygen, is one of the more challenging tasks. The end-to-end resistance of the ceramic coating was initially 150 kΩ and after venting to atmosphere reached ~10 MΩ. After approximately two months under storage vacuum, a hypot test at 1 kVDC measured the film resistance as an acceptable ~600 MΩ. The ceramic break was then kept under storage vacuum and the time at atmosphere was minimized during installation.

The coating film is in the present unit connected to the metal cuffs by spring finger rings which could be avoided by pre-coating the ceramic with MoMn+Ni bands.

HOM Q-MEASUREMENTS

The demonstration of FB damper properties is based on HOM Q-measurements. Network Analyser (NA) S_{21} transmission can be performed between pickup (PU) probes or alternatively between the PU and a power coupler (PC). The installed gun cavity has a dual-feed fundamental power coupler (FPC) composed of two coaxial type couplers, two three-stub waveguide phase shifters, located symmetrically in each arm of the coupling system, and a waveguide shunt-T RF power splitter. The two coaxial couplers are located opposite to each other on the cavity beam pipe to minimize the transverse beam kick. The original VTF gun cavity measurements were made at JLAB between PC and PU. The measurements on the ERL gun were made from FPC to PU, and measurement on the large grain cavity from a PC probe to PU. The Qs taken without ferrite at a few low frequencies are shown in Fig. 3 together with the original VTF data. The lower than expected Q values are attributed to strong radiation into the FPC. [6].

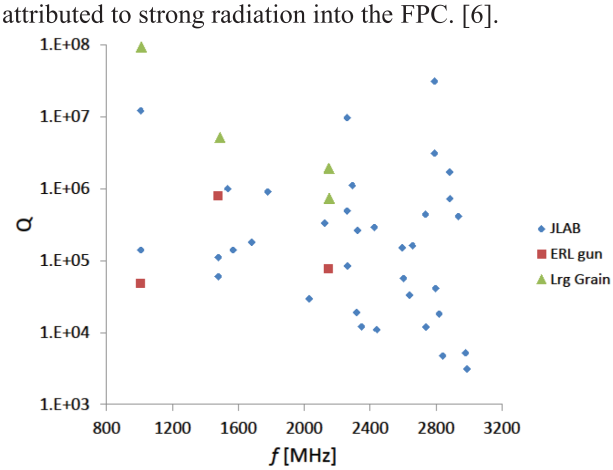

Figure 3: Cavity Q-values collected for the gun and the large-grain cavities at 2 K.

The analysis for the dipole resonances at 2.1458 GHz is found in Fig. 4. The dipole cavity resonances are typically split and the S_{21} curves can have non-standard shapes. The dual-feed coupler allows shifting one arm to change the resonance frequency by up to 0.7 MHz resulting in a multitude of curves and slightly different Q-values as seen in Fig. 5.

In order to simplify the search for and identify the HOM resonances, the S_{21} transmission was scanned from 700 to 3000 MHz in sections of 10 MHz. The frequency span was limited for time reasons although a high Q measurement demands a span of <1 MHz. Five scan sections around 2.1458 are re-assembled into Fig. 6. The highest Q in the ERL cavity was measured as 3.1×10^7 in the split resonance at 2.7917 GHz with the scan sections around it seen in Fig 7.

ISBN 978-3-95450-143-4

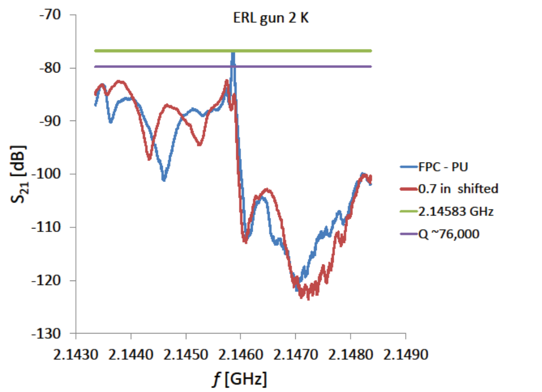

Figure 4: Q-measurement of the dipole 2.1458 GHz.

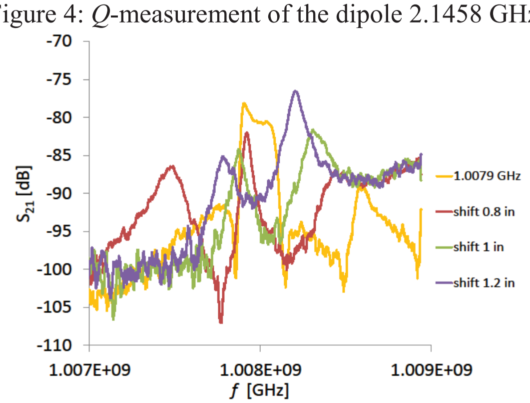

Figure 5: Shifting of the S_{21} curve by one FPC arm.

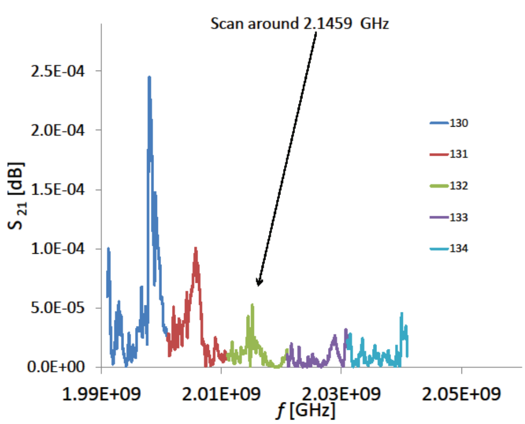

Figure 6: Concatenated five scans around 2.1458 GHz.

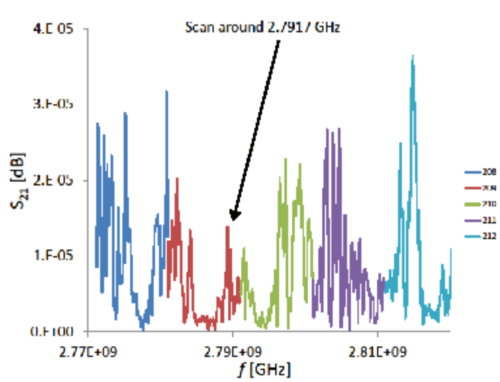

Figure 7: Concatenated five scans around 2.7917 GHz.

FERRITE BREAK SIMULATIONS

Due to technical and scheduling problems, the SC measurements of the FB had to be delayed. Establishing the damper properties can be done by simulations with the CST Microwave Studio or the Wolfram Mathematica program. The FB can be simplified into a structure with a radial sequence of circular symmetric layers. The short axial length and the presence of the metallic boundary disks points to the treatment as "radial" transmission line [7]. The difficulty in analysing a structure with layers, mm thick, was overcome by using an analytical matrix method. The FB damping property is given by the impedance at the gap in the beam tube. Using a $\mu \approx 29/(1+j2.5 f_{\mathrm{MHz}})$ and $\varepsilon \approx 13$ [8] for the ferrite and $\varepsilon \approx 9$ for the alumina, the simulated impedance in Fig. 8 was obtained.

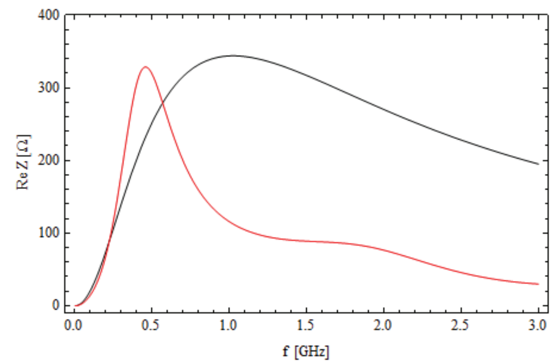

Figure 8: FB impedance at beam tube in red, ferrite alone in black.

CONCLUSION

Although still dependent on confirmation at SC temperatures, the Ferrite Break damping properties seem adequate for its use in the ERL SC cavity. The separation of the damper proper from the cavity vacuum represents a major operational advantage. The two-component concept provides a great flexibility in the choice of the damper material. The ferrite break deserves further investigations.

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