LONGITUDINAL IMPEDANCE MEASUREMENTS OF AN RK-TBA INDUCTION ACCELERATING GAP

S. Eylon, E. Henestroza, J.-S. Kim, Fusion and Accelerator Research, San Diego, CA 92122
T.L. Houck, G.A. Westenskow, Lawrence Livermore National Laboratory, Livermore, CA 94551
S.S. Yu, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Abstract

Induction accelerating gap designs are being studied for Relativistic Klystron Two-Beam Accelerator (RK-TBA) applications. The accelerating gap has to satisfy the following major requirements: hold-off of the applied accelerating voltage pulse, low transverse impedance to limit beam breakup, low longitudinal impedance at the beam-modulation frequency to minimize power loss. Various gap geometries, materials and novel insulating techniques were explored to optimize the gap design. We report on the experimental effort to evaluate the rf properties of the accelerating gaps in a simple pillbox cavity structure. The experimental cavity setup was designed using the AMOS, MAFIA and URMEL numerical codes. Longitudinal impedance measurements above beam-tube cut-off frequency using a single-wire measuring system are presented.

1 INTRODUCTION

A greatly simplified gap, using high-gradient insulator (HGI) technology, has been designed for the induction modules of a proposed RK-TBA rf power source [1]. These insulators, comprised of finely spaced, alternating dielectric and metal layers, have demonstrated factors of 1.5 to 4 times the vacuum surface flashover capability of insulators made from a uniform dielectric [2,3]. HGI's have maintained similar capability in the presence of an electron beam [4]. These characteristics allow more flexibility in the positioning of the insulator and the overall gap design. In typical induction accelerator designs [5], the gap is shaped to accommodate an extended insulator that is hidden from line-of-sight view of the beam. The shape of the gap must be carefully designed to minimize field stress on vacuum surfaces. An issue that needs to be addressed concerning the placement of a stacked insulator in an accelerating gap involves the interaction impedance of the integrated module/insulator with the beam. The concern is that the multilayered stacked geometry would generate additional resonances compared to a solid insulator, and that these new resonances would have unacceptable impedance. The transverse impedance characteristic of accelerating gaps using HGI's is presented elsewhere in these proceedings [6]. In this paper we present experimental and computational measurements of the longitudinal impedance of a pillbox cavity with a HGI insulator.

2 SIMULATIONS OF HGI PERFORMANCE

URMEL simulations were performed to provide an intuitive feel for the effect of electrodes placed in an insulator. The gap design simulated was a simple pillbox cavity with the same geometry used in the impedance measurements. A schematic of the pillbox geometry is given Fig. 1. . The simulated insulator varied in the number of electrodes (conducting disks), but maintained overall dimensions of width 1.3 cm with inner/outer radius of 2.4/4.9 cm. A summary of results of the simulations for the lowest modes is given in Table I. The cutoff frequency for the simulated cavity is 4.8 GHz. The URMEL results indicate that while additional resonances are generated, their R/Q is not significant. Impedance spectrums generated by AMOS simulations of similar cavities including rf absorbers displayed no additional impedance peaks. Comparison of AMOS simulations and experiments are presented below.

3 EXPERIMENTAL SETUP

Longitudinal impedance measurements up to 20 GHz were performed on a pillbox cavity configuration using a wire transmission line system developed by LBNL [7]. Special techniques were implemented in the system to allow the frequency range to be extended well above the beam tube cutoff frequency. These techniques also allow accurate measurements of very low impedance in the heavily damped acceleration gap structures. The absolute error can be kept to less than 2 ohms. Both features are important. For the RKTBA application, the beam pipe cut off frequency is about 4 GHz while the longitudinal modulation of the beam current is 11.424 GHz. In

Table I. Summary of pillbox cavity modes from URMEL simulations for different numbers of intermediate electrodes in the insulator. Although more resonances are created with increasing number of electrodes, their R/Q's are negligible.

Solid		One Electrode		Three Electrodes		Five Electrodes	
Freq (GHz)	R/Q (Ω)	Freq (GHz)	R/Q (Ω)	Freq (GHz)	R/Q (Ω)	Freq (GHz)	R/Q (Ω)
0.986	16.2	0.958	15.2	0.894	13.3	0.814	11.4
2.820	6.95	2.841	6.38	2.893	5.23	2.940	4.13
----------	----------	----------	----------	----------	----------	3.483	0.027
----------	----------	----------	----------	3.576	0.007	3.636	0.000
4.182	3.35	4.165	3.18	4.140	2.798	4.097	2.35

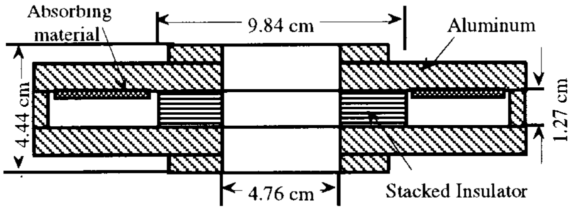

Figure 1. Illustration of the test pillbox cavity.

addition, the desired impedance at 11.424 GHz is only 2.5 Ω. Fig. 2 shows a schematic of the impedance measurement setup. The pillbox is positioned between two sections of transmission line with a characteristic impedance ZL of 160 Ω. The transmission line inner diameter is 4.76 cm and the center wire diameter is 0.32 cm. To ensure accurate positioning, a Styrofoam guide is used to centered the wire in the beam line. Two conical, electroformed Chebyshev tapers are used for matching the transmission line impedance to the 50 Ω lines attached to the inputs of a HP8510B network analyzer.

In the above wire measurement, the matching tapers have been design to be free of TEM reflections over the range of 100 MHz to 20 GHz. The tapers, however, are not matched for traveling waveguide modes (TWs). TWs could be reflected from the tapers and lead to standing waves in the system producing erroneous results. To prevent TW reflections, absorbing material (Emerson & Cuming Eccosorb AN73) was placed between the pillbox and the tapers. The transmitted TEM signal is also attenuated, but the network analyzer has sufficient dynamic range to accommodate the reduced signal.

For test cavities occupying a limited length of the transmission line, the impedance, Z_B, is calculated from:

$$Z_B = 2Z_L\ (S_{21ref} / S_{21obj} - 1),\ \text{where}$$

S_{21ref} is the system response when replacing the test cavity with a smooth tube having the same longitudinal length, S_{21obj} is the test cavity (pillbox) response, and Z_L is the characteristic impedance (160 Ω) of the beam tube transmission line.

The test pillbox cavity represents a simplified version of an induction accelerator module and gap. Refer to the illustration in Fig. 1. The geometry of the pillbox was varied by including a metallic ring, ID/OD 14.9/16.2 cm, attached to one wall of and extending 1 cm across the cavity dividing the pillbox into two chambers. Absorbing materials in the form of ferrite tiles or foam bands (Emerson & Cuming Eccosorb AN73) were inserted in the pillbox to suppress trapped resonances. A solid rexolite insulator was used to establish a base impedance for the pillbox. The stacked insulators were alternating layers comprised of thin washers (flatten toroids) of mylar (7.5 mils per washer) and copper (5 mils per

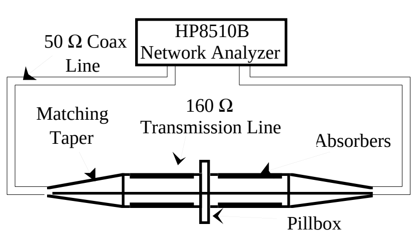

Figure 2. Impedance measurement setup.

washer). The number of washers of mylar and copper per layer could be varied. For the majority of the measurements, the inner diameter of the rexolite and stacked insulators was equal to that of the pillbox, 4.76 cm, and the outer diameter was 9.84 cm. Measurements were also taken for a solid rexolite insulator recessed into the pill box with inner diameter of 7.30 cm and outer diameter of 9.84 cm.

4 MEASUREMENTS

Samples of the measurements are shown in Fig. 3, 4, and 5. For these measurements, the pillbox arrangement is as illustrated in Fig. 1. The absorbing material was a mosaic of ferrite tiles placed to approximate a solid toroid. Figure 3 compares three different gaps widths using a stacked insulator with a 1.5:1 ratio (alternating layers of 7.5 mil mylar and 5 mil copper) of insulator to conductor. Copper washers, with radii equal to the insulator washers, were stacked in the gap to adjust the width. Peak impedances of resonances below the cutoff frequency vary linearly with gap width. Above cutoff, the peak impedances varied from this scaling.

An important purpose of the measurements was to validate the induction cell design code, AMOS, for simulation results above the beam pipe cut-off frequency. Two difficulties were encountered when attempting to simulate the measurements. First, the rf characteristics of the damping ferrites were not known. The simulations modeled the TDK PB11b ferrite which appeared to be more efficient at damping than the actual ferrite used in the pillbox. Also, the rectangular ferrite tiles used as rf absorbers could not be tightly packed and only approximated the toroid modeled in the simulations. This could also explain some of the difference in damping between the simulated PB11b ferrite and the actual ferrite. Qualitative agreement can be seen between measurements and simulations in Fig. 4 and 5. The simulation results were adjusted about 4% in frequency to match resonant peaks. The measurements in Figure 5 were a more demanding test as the stacked insulator was included in the simulation.

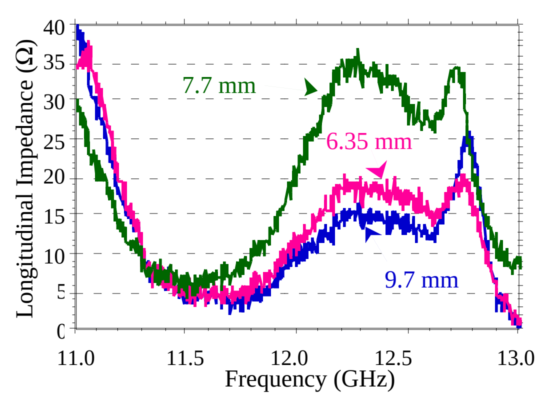

Figure 3. Effect of different gap widths on Z_L. Above the cutoff frequency, peak impedances did not obey the linear scaling with gap width predicted by analytical theory.

5 CONCLUSIONS

Observations made during the measurements include:

(1) Analytical theory for impedances above cutoff has addressed resonant peak impedances [8]. In general, the theory is in agreement with the measurements performed where the gap width is taken to be the insulator width minus the conducting layers. Theory is not useful for estimating the impedance spectrum between peaks.

(2) Changes to the geometry of the interior of the pillbox (adding an intermediate ring to change the effective OD) had negligible effect on the impedance spectrum well above cutoff.

(3) Reducing the gap width generally reduced resonant peaks with minimal effect on the “valleys” between peaks, and did not shift peaks, or valleys, in frequency.

(4) The placement of the conducting layers in the insulator does not have a significant effect on the impedance spectrum of the pillbox.

(5) Recessing the insulator from the beam tube reduced the impedance in general.

(6) Increasing the damping can lower the peak resonant values, but tends to increase the minimum value of the “valleys” between peaks.

Two primary objectives were accomplished. Very low longitudinal impedances (~ 2 ohms) were obtained and measured for the cavity geometry of interest. Also, consistent qualitative agreement was found between measurements and AMOS simulations.

6 ACKNOWLEDGMENTS

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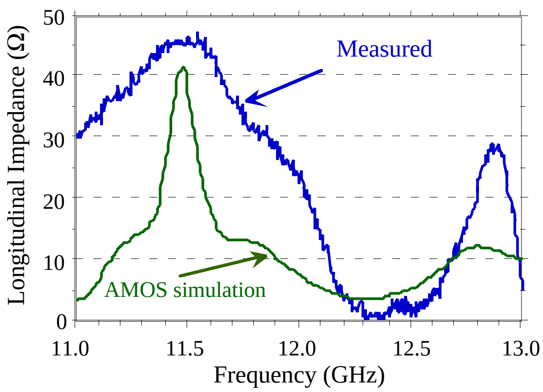

Figure 4. Comparison of measurement and simulation for a solid rexolite insulator.

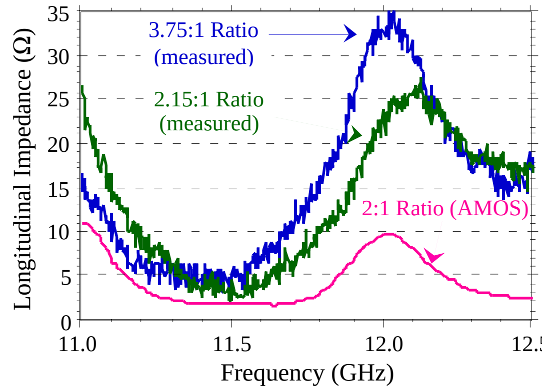

Figure 5. Comparison of ratios of insulator to conductor thickness in the stacked insulator. Decreased effective gap width generally reduced resonant peaks with minimal effect on the “valleys” between peaks.

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