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BEAM DRIVEN BIMODAL CAVITY STRUCTURE FOR HIGH GRADIENT ACCELERATION*

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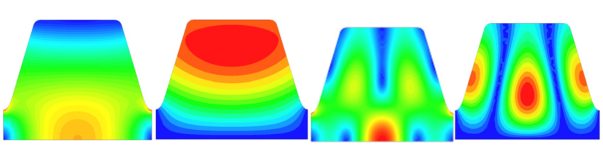
Abstract

Research aiming to increase the RF breakdown threshold in electron/positron accelerators is being conducted at the Yale University Beam Physics Laboratory. Our two-beam accelerator approach employs a beam driven bimodal cavity structure. This cavity includes (i) two modes excited by the drive beam, with the higher mode frequency three times that of the fundamental TM010 mode; (ii) a low-current accelerated beam and high-current drive beam traversing the same cavity structure. This approach has the potential advantages of (a) operating at higher acceleration gradient with lower breakdown and pulsed heating rates than that of a single-mode cavity structure at the same acceleration gradient, due to the spatiotemporal field distribution properties in the bimodal cavities; and (b) obtaining high accelerating gradient with a low energy drive beam. Recent progress in simulations and work towards an experimental test stand are presented.

INTRODUCTION

Surface RF pulsed heating is considered as one of the major causes of RF breakdown which limits the acceleration gradient to be less than about 150 MV/m in conventional metallic X-band accelerator structures. A higher breakdown threshold would be desirable for a multi-TeV machine. One novel cavity design we proposed for this application is the electron beam driven bimodal cavity structure, using a superposition of multi-harmonic modes to suppress pulsed heating and RF breakdown [1-4].

The RF electromagnetic field distributions in a multi-harmonic cavity with fundamental TM-010 mode and its 3rd harmonic TM-012 mode are shown in Fig. 1. Its RF properties and features in RF breakdown suppression is described in Refs. [3-4]. The superposition of fields from these two modes introduces a possible mechanism to suppress RF breakdown.

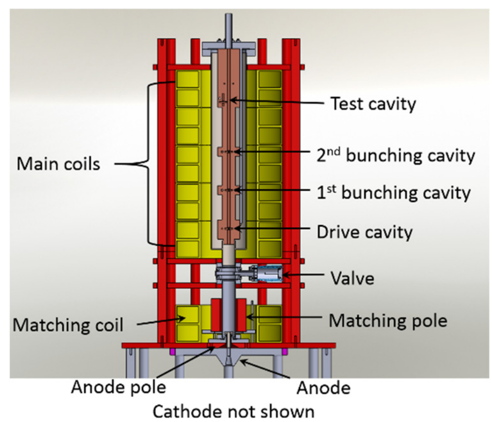


(a) (b) (c) (d)

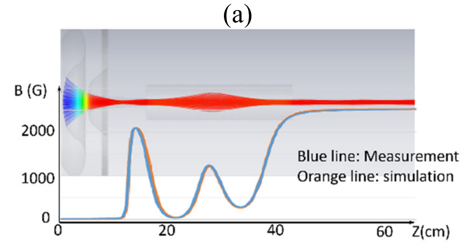
Figure 1: (a) Bimodal cavity electric and (b) magnetic field distributions for TM010 mode; (c) electric and (d) magnetic field distributions of its 3rd harmonic TM012 mode.

Our drive beam test stand under development to test bimodal cavities has a maximum beam energy of 500 keV. Consequentially, drive beam particles would be reflected at sufficiently high field gradient in the test cavity were both beams to move collinearly. Therefore our design has the drive and test beams not moving collinearly, even as the beams are essentially in the same composite cavity. This approach allows evaluation of RF breakdown results predicted by our theory as would apply to collinear beams in a bimodal cavity with a higher energy drive beam that would not experience particle reflections.

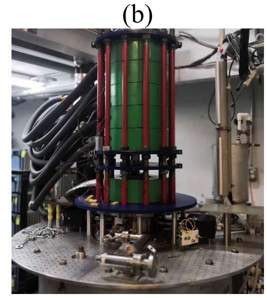
EXPERIMENTAL DESIGN AND SIMULATION



(a)



(b)



(c)

Figure 2: (a) Engineering design of the test stand setup. (b) End-to-end tracking simulation of beam and magnetic field distribution along axis. (c) Assembled test stand, showing magnetic system on top of 500kV/218A gun tank.

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The engineering design of the system are partially shown in Fig. 2. The overall system includes the beam matching system, beam bunching cavities, test cavity, and magnetic field system. Beam tracking simulations indicates that the beam can be confined within a 6 mm diameter pipe with a solenoidal magnetic field of 2.3 kG or higher.

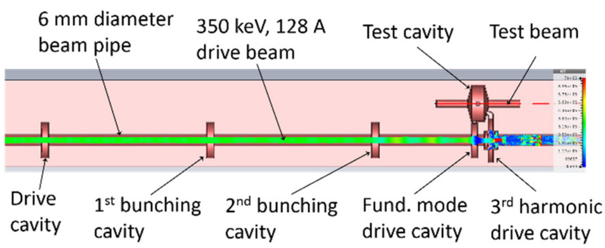


Figure 3: Top view of the half split of the cavity system.

As shown in Fig. 3, the beam transport line are designed to be in two split pieces for simplified machining, avoiding brazing, and tuning. The system includes a drive cavity, two bunching cavities, and a composite test cavity. Drive cavity power is about 30 W at 11.424 GHz. The bunching cavities are detuned by about +35 MHz. The distances between the drive cavity and first bunching cavity, and between the two bunching cavities, are 10 cm; while the distance between the 2nd bunching cavity and the composite test cavity is 7 cm. Examples are shown below for a drive beam energy of 350 keV and a current 128 A, consistent with our gun's 0.62 μperv perveance; this is well below its full 500 keV, 218 A capability.

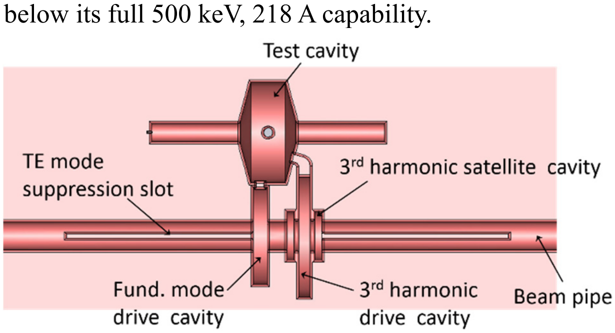
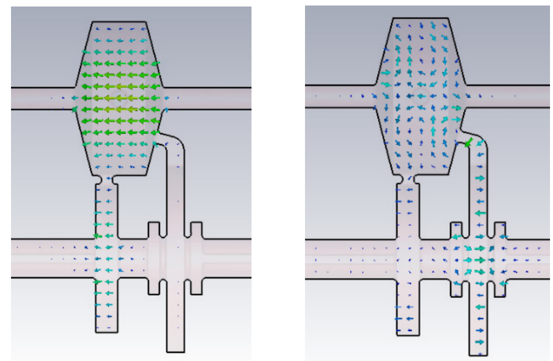


Figure 4: Half split view of the composite drive and test cavity structure. The test cavity radius is 10.8 mm, the fundamental mode drive cavity radius is 10.4 mm, the 3rd harmonic drive cavity radius is 13.1 mm.

Test cavity are shown in detail in Fig. 4. The drive beam goes from left to right. The vertical slots on both sides of the test cavity are to suppress possible TE mode excitation in the beam pipe. The 3rd harmonic drive cavity is designed to operate in theTM030 mode to optimize its coupling to the 3rd harmonic mode in the test cavity. The large pipe diameter needed to accommodate the high current beam is not cutoff at the 3rd harmonic. So choke cavities are used to prevent leaking from the 3rd harmonic drive cavity and, not-incidentally, to increase the transit-time factor.

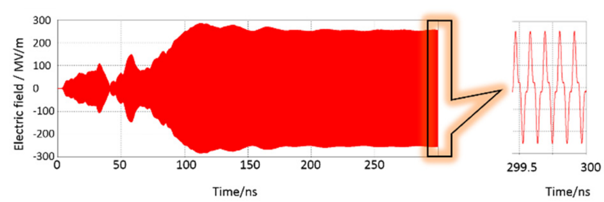
Bimodal two-frequency excitation of the system has been simulated using CST microwave studio. Field distributions are shown in Fig. 5. The phase between the modes can be adjusted by changing the separation between the two drive cavities. The location of the 3rd harmonic coupling slot is where the 3rd harmonic magnetic field is strongest.



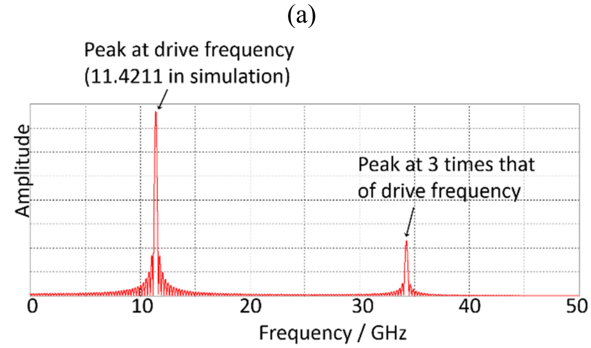
(a) (b)

Figure 5: (a) Fundamental and (b) 3rd harmonic electric field ditributions. Both modes have Q of about 7400.

Beam dynamics simulations were performed with CST PIC particle studio. The electric field along the axis *vs* time after beam entry at the center of the test cavity are shown in Fig. 6a. The peak field at steady-state reaches 256 MV/m. The peak energy gain of the low-current test beam is 1.68 MeV, while the drive beam energy is only 350 keV and no drive electrons are reflected. The system reaches steady state after 120 ns, which is longer than what is expected from the Q factors, possibly because of the interaction between the cavities *via* the electron drive beam. The amplitude of the fundamental mode is 197 MV/m and that of the 3rd harmonic is 59 MV/m, from the Fourier analysis of the signal. The detailed view of the signal in Fig. 6a also shows that the relative phase of the two modes is also close to the optimized phase. Fig. 6b shows the Fourier transform of the test cavity *E*-field after steady-state is reached.



(a)



(b)

Figure 6: (a) Axial electric field strength at center of the test cavity. (b) Fourier transform of the signal at steady state.

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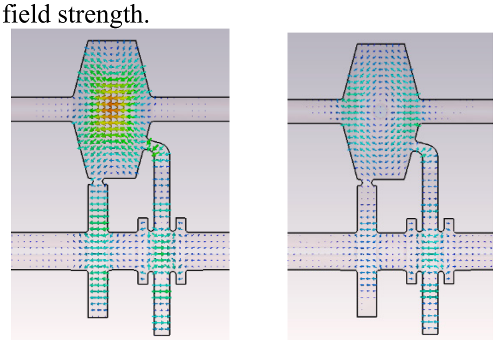
It is found that the peak electric field on the cavity surface is relatively uniform in our cavity, from 120 MV/m to 170 MV/m. Figure 7 shows the composite beam-driven electric field distributions at peak and minimum center point field strength.



(a) (b)

Figure 7: (a) Electric field distributions at the center point at its peak field gradient (256 MV/m); and (b) its zero field gradient.

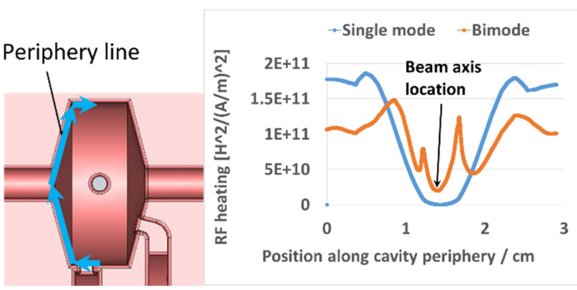


Figure 8: Comparison of RF pulsed heating (proportional to $<H^2>$) for our cavity operated with one mode and bimodally, plotted along the cavity periphery. Both cases are for a peak accelerating gradient of 256 MV/m.

The simulation case shown in Fig. 6 and 7 was not well optimized to minimize the RF pulsed heating on the cavity surface. For that example, the 3rd harmonic amplitude is 30% that of the fundamental, the peak RF pulsed heating is 20% less than that in a single mode cavity with the same peak accelerating field gradient (256 MV/m), as shown in Fig. 8. More reduction in the peak RF pulsed heating is expected after optimization. Extraolating from that example, one may infer that the peak RF pulsed heating would be 28% less than for a single mode cavity at the same peak accelerating field gradient, where the 3rd harmonic amplitude is 25% that of the fundamental.

A two-segment split cavity cold-test prototype with its split gap adjustable from 0 to 1 mm has been designed, constructed and tested shown in Fig. 9. The tested RF parameters are consistent with simulation results.

(a) (b)

Figure 9: (a) top view and (b) bottom view of a cavity split.

The DTI high voltage Marx-bank modulator has been modified and conditioned. Tests so far have generated pulses up to 400 kV and 156 A into a resistive dummy load. Figure 10 shows the HV pulse after initial pulse shaping adjustment of the system. Final adjustments are to be made after the modulator is operating into a "perveance load."

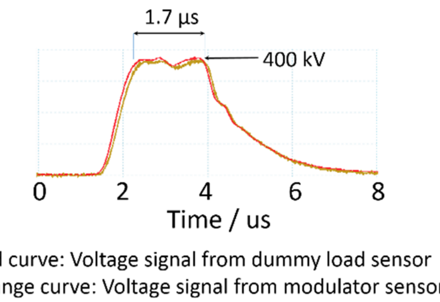


Figure 10: DTI HV modulator output pulse on a 2.56 kΩ resistive dummy load.

Further modification of the DTI modulator was required to permit operation of the 350 W filament supply into the relatively low 0.27 Ω filament resistance for a replaced cathode. Tests with the newly-installed cathode stem for the 500kV/218A gun are about to begin at this writing.

CONCLUSION

A beam driven bimodal accelerator structure with probability of lower surface pulsed heating than can be realized with single-mode cavities is under test in the Beam Physics Laboratory at Yale University. Simulations indicates that more than 250 MV/m of peak accelerating field at the cavity center could be achieved in our system under conditions where pulsed surface heating would be expected to be at least 20% lower than would be the case for single mode operation at the same acceleration gradient. This finding augers well for high-gradient acceleration with reduced RF breakdown probability.

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