HIGH POWER TESTING OF A FULLY AXISYMMETRIC RF GUN*,**

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Abstract

Advanced Energy Systems (AES) has developed a fully axisymmetric radiofrequency electron gun with an upstream power feed. High power RF testing has been performed on this novel structure at a frequency of 11.43 GHz using the magnicon facility at the Naval Research Laboratory (NRL). The successful testing proved out the basic design features of the gun. The overall design of the gun is discussed along with the results of the high power RF testing.

INTRODUCTION

The patented gun design (US Patent No. 7,116,064) incorporates full axial symmetry in order to eliminate any emittance growth from higher order multipole RF fields and to allow optimal placement of the emittance compensation solenoid. The rear input coupling feed also allows isolation of the cathode from the main gun body and opens up the downstream area for diagnostics, magnetics, laser ports, etc. The fabricated gun contains 1.6 cells, utilizes coaxial coupling from the upstream end of unit and allows for axisymmetric tuning of both the cathode cell and the second accelerating cell. Although the present design is at 11.43 GHz, the basic design features are scalable to any frequency. The features of the gun have been proven to operate at high gradients.

DESIGN

The fundamental goal of the project was to design a flexible, fully axisymmetric gun that has the potential to achieve the lowest possible transverse emittance.

All radial structures such as coupling slots, tuning slugs, laser ports, pickup ports, etc have been eliminated. The cells themselves are of the standard pill-box type. Figure 1 shows a cross-section of the gun. The input power is fed from a rectangular waveguide through a waveguide-to-coaxial adapter. The RF power then travels down the coaxial line and into the cathode cell of the gun. The cathode itself is contained on the tip of the coaxial line center conductor. In the present case, the center conductor is solid copper, however other materials could be placed at the tip for alternate cathode materials. The center conductor is fixed on its other end to a micrometer. This allows the center conductor to be used for tuning the cathode cell. For non-metallic cathodes, the center conductor can be fully withdrawn for cathode deposition and processing.

A second cell is included with the specific design developed in this project. As usual, the power coupling between cells is through the on-axis iris opening. The second cell also incorporates an axisymmetric tuning mechanism that uniformly pushes and pulls on the end wall of this cell.

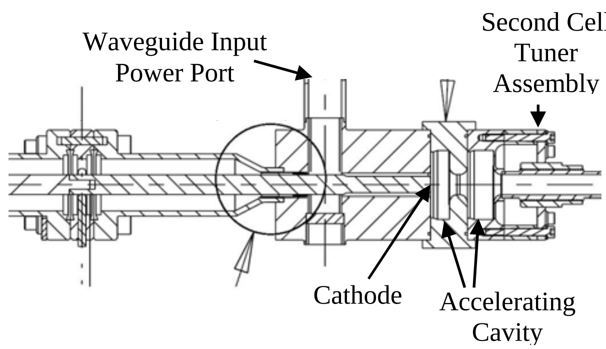

Figure 1: Cross-Sectional View of Gun Assembly

The input power coupling mechanism is by nature well suited for strong coupling and has been considered for superconducting guns [1] and high average current normal conducting guns [2]. In the case of this gun, since it is a low duty factor x-band design, the coupling had to be limited. One way to achieve this is by setting up the design such that the coaxial line supports a standing wave. To further reduce the coupling, a step was incorporated in the center conductor at the interface between the rectangular waveguide and the coaxial portion. Additionally, the coupling can be controlled through the diameter of the center conductor, allowing for easy post fabrication coupling modification through replacement of the center conductor.

TESTING

Low power testing was first performed on a cold model. Based on the results of the cold model, the final hot model was fabricated and testing took place at the magnicon facility located at the Naval Research Laboratory (NRL).

Cold Model

The cold model was fabricated from copper and was mostly brazed together so that the cold model could also be used for testing fabrication methods. The assembled cold model is seen in Fig. 2.

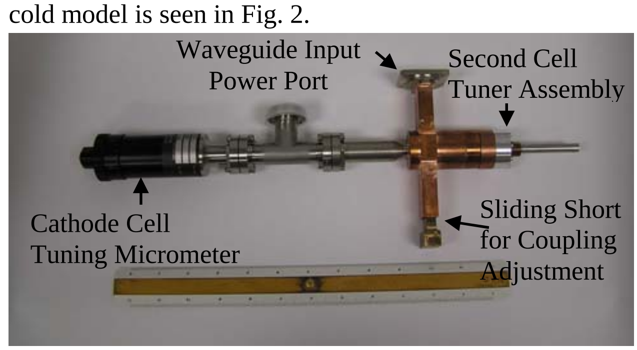

Figure 2: Gun cold model assembly.

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The photograph shows the linear actuator that controls the center conductor on the left side of the assembly. The second cell tuning mechanism is the aluminum cap seen on the right side of the assembly. The waveguide input flange is seen above the left hand side of the copper body. On the lower side is an adjustable short that is used to adjust the input coupling into the accelerating structure. On the hot model the waveguide short position is fixed. Using this cold model, measurements were made of the cell 1 frequency, cell 2 frequency, coupling into cell 1, and tuning mechanisms for cells 1 and 2. These measurements were compared to calculations made using SUPERFISH and are presented in Table 1.

Table 1: Cold test results compared to calculations.

	measured	**calculated**	
cell 1 frequency	11.390	11.385	GHz
cell 1 tuning	4	6	MHz/mil
cell 2 frequency	11.234	11.193	GHz
cell 2 tuning	6	5.5	MHz/mil

The measured numbers agreed quite well with the calculations. The largest discrepancy was in the cell 1 tuning, which was determined to be due to differences in the corner radius at the outer edge of the inner conductor. A larger corner radius on the end of the center conductor results in a decreased tuning rate. These tuning rates are sensitive enough to make up for relatively large final assembly frequency errors while still allowing sufficiently fine tuning.

Hot Model

Due to time and monetary constraints a set up for electron beam testing could not be accomplished. Thus, the hot model testing was confined to high power RF testing. This testing was performed at the NRL magnicon facility.

Tuning of the hot model proceeded smoothly, and post-braze fine-tuning was readily accomplished using the built-in mechanisms. The only issue that arose was with the input coupling, whose final value was close to 0.5. Although the design flexibility of the gun afforded the potential to install a modified center conductor to provide for increased input coupling, overall programmatic timing considerations did not allow the delay this would have entailed. When final tuning was completed, the gun assembly was baked and transported to the test facility.

Due to the lower coupling, high power tests were performed with both cells tuned and with the second cell detuned in order to provide a better input match.

Figure 3 contains a series of oscilloscope plots showing the modulator pulse, the forward power in both arms of the magnicon output, and the reflected signal from the gun. Tests showed that the matched arm of the magnicon was not affected by the gun mismatch.

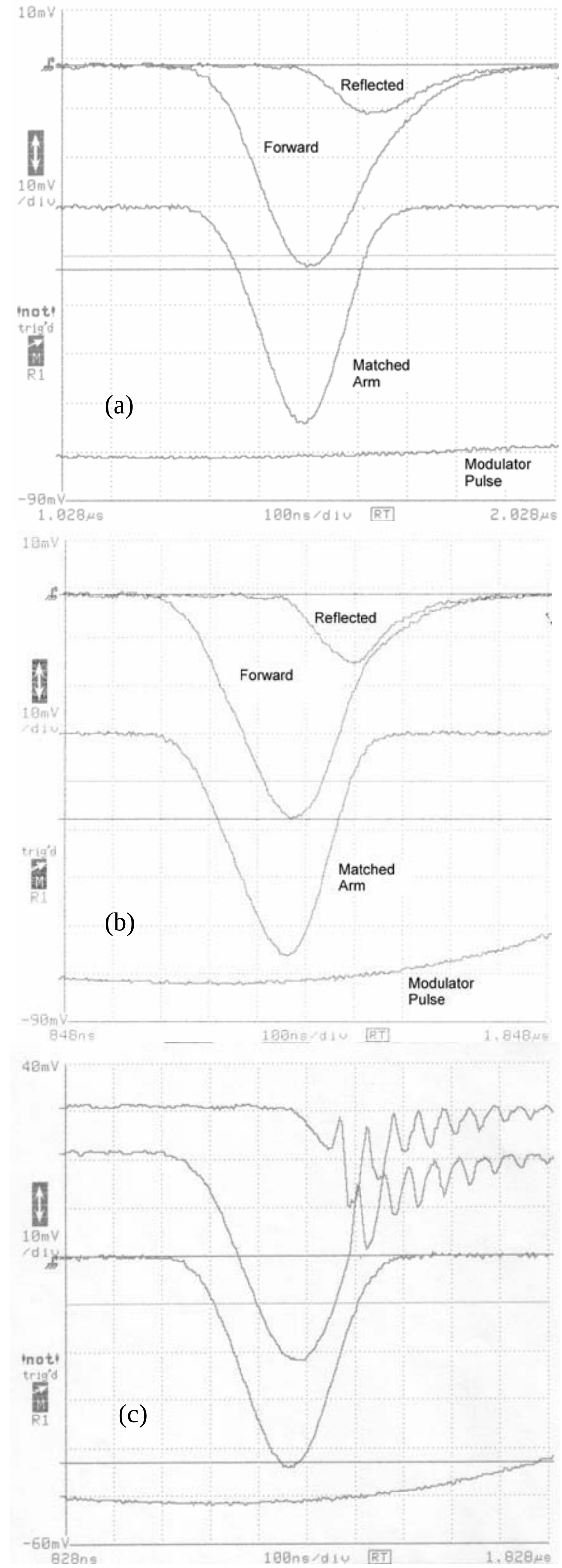

Figure 3: Forward and reverse power in gun arm and forward power in orthogonal arm of magnicon for a) long modulator pulse, b) short modulator pulse, and c) showing a breakdown event. Note in (c) that the matched, orthogonal magnicon arm is not affected by the breakdown in the gun.

Testing started with a relatively long magnicon pulse, shown in Fig. 3a, but this limited the repetition rate to one to two pulses per second due to system considerations. Under these conditions conditioning proved to be too difficult. Shortening of the magnicon modulator pulse, shown in Fig. 3b, did not substantially affect the RF pulse but allowed the repetition rate to be increased up to six pulses per second. Figure 3c shows an example of a breakdown event.

The conditioning history of the gun is presented in Fig. 4. Conditioning proceeded quite rapidly to above 200 MV/m. Consistent operation was achieved at 240 MV/m, and the maximum gradient reached was 255 MV/m. Conditioning was terminated early on the third day.

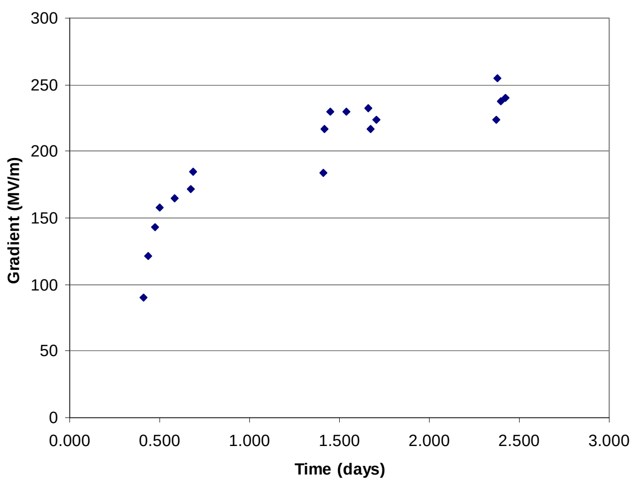

Figure 4: Conditioning history of gun showing calculated gradient as a function of time.

After conditioning, the center conductor of the coaxial input coupler was removed from the system for inspection. Evidence of breakdown was clearly evident as anticipated. The interior of the gun itself could not be inspected due to the small tubes, but it is expected that virtually all of the breakdown occurred in the coaxial feed section. Photos of the inner conductor of the coaxial feed are shown in Fig. 5.

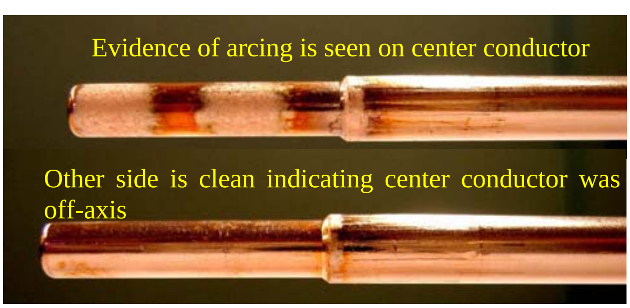

Figure 5: Photos of center conductor after conditioning.

It is evident from this figure that the breakdown was not azimuthally symmetric indicating that the center conductor was not exactly centered. There are three regions of breakdown. The region of breakdown seen in the center of both photographs occurs at the step in the rod that was placed at the interface between the waveguide and the coaxial line. This breakdown occurred the full 360 degrees around the conductor, but was concentrated to one side due to the probable misalignment. The step was placed in the piece to reduce the coupling but actually proved unnecessary since the final input coupling was too low. It is easily removed in future designs, and these designs will benefit from the increased coupling. A slight overcoupling is actually preferred in pi-mode RF guns for the improved fill time and reduced fill transients that the overcoupling provides.

The other two regions of breakdown are only evident in the upper photo of the figure. The other side of the center conductor shown in the lower photo is still clean, which is a clear indication of misalignment of the center conductor. The two breakdown regions correspond to the peaks of the standing wave pattern in the coaxial section. The standing wave minimums do not show any evidence of breakdown. Future work should include simulations of the effect of center conductor misalignment. For a standing-wave design of this type, an optimization study to reduce the field levels in the coaxial region to minimize the breakdown effects of any misalignment would also be useful. The high coupling factor designs that can utilize a traveling wave in the coaxial portion should not suffer from breakdown in this region.

A very important positive indication is the lack of breakdown evidence at the tip of the center conductor, the edges of which can be seen in Fig. 5. The radius on the corner still appeared clean as did the face of the center conductor end, which is the cathode surface. The lack of breakdown in this area is a positive indication that the overall concept is capable of higher gradients than achieved during this testing.

ACKNOWLEDGEMENTS

The author would like to thank Steve Gold and his coworkers at the NRL magnicon facility for their help and flexibility during the high power testing. Thanks are also extended to the Department of Energy for their support if this project through the DOE SBIR program.

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