WITNESS GUN FOR THE ARGONNE WAKEFIELD ACCELERATOR

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I. INTRODUCTION

The witness gun [1] for the Argonne Wakefield Accelerator (AWA) is a six-cell, copper, iris loaded, rf photocathode operating at 1.3 GHz in a π/2 standing wave mode. An intense drive beam (up to 100 nC @ 20 psec FWHM) will be used in the AWA project [2] to excite (i.e. drive) wakefields in at least two separate test devices: a dielectric loaded cylindrical waveguide and a plasma cell. In both cases a low charge, low emittance witness beam (0.1 nC charge, 1 πmm-mrad 90% physical emittance) is required to probe (i.e. witness) the wakefields left behind by the drive beam [3]. This paper will primarily discuss the recent progress in the construction of the witness gun, while also briefly summarizing the central design issues of the gun. A brief status report on the dielectric witness gun option is also included. We conclude with a short statement on our near term future plans.

II. MARK IV TYPE WITNESS GUN

The conventional copper rf photocathode gun that we have selected to build is actually a scaled down version of the s-band Mark IV accelerator that was used at SLAC, as described in reference [1]. Since the Mark IV Accelerator was a linac, some adjustments were made to turn it into a photocathode using the rf design code URMEL. The witness gun (fig 1) has a photocathode (dark square) in the first 1/2 cell, a coupling iris in the fourth full cell and a beam exit hole in the last half cell.
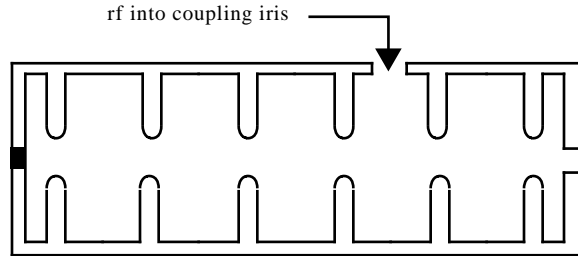
rf into coupling iris ⎯⎯⎯⎯⎯

Figure 1 The Mark IV Witness Gun with Coupling Iris and photocathode (dark square) shown.

In order to probe the test devices properly, the witness beam must have a kinetic energy of four to five MeV, a physical emittance of 1 πmm-mrad, an energy spread of less than 1% and a bunch length of about 5 psec. Extensive simulations with PARMELA have shown the Mark IV type gun to be capable of achieving the design parameters. Using a 1.5 mm spot size and a phase launch of 65 degrees we obtain the following results

Energy	90% Emittance	Energy Spread	Bunch Length
4.53 MeV	0.76 πmmmrad	0.5% FW	5.6 psec

A. Construction: Tuning and Matching

When constructing a resonant structure, such as an rf photocathode, one attempts to use an electromagnetic mode solver, like URMEL, to obtain the cavity dimensions. However, the dimensions given by such a code can only serve as an approximation to the parameters shown in figure 2. Therefore, some dimensions must be left undercut so that the resonant frequency of the gun can be fine tuned by making small machine cuts. The problem of matching or coupling rf to the gun appears to be intractable by any means except tedious iterations of cutting and measuring. In any case, the authors of this paper are unaware of either analytic or computer techniques capable of ameliorating this problem.

While radius b is used to set the resonant frequency of the gun, the other dimensions (fig 2) are arrived at in the following manner. The cell length d is chosen by setting the phase shift (Δϕ) equal to the desired value (π/2 in the case of the witness gun) and then satisfying the relationship

$$\left(\frac{2\pi}{\Delta\phi}\right)d = \frac{v_{phase}}{f}$$

Once d is fixed, the remaining parameters a and t (fig 2) are chosen as a compromise between optimizing for mechanical strength, high shunt impedance and strong cell-to-cell coupling. Thin irises walls (small t) and large iris radii (large a) give strong cell-to-cell coupling which is desirable, but these values also give low shunt impedance which is undesirable. For an excellent discussion of the problem of tradeoffs and the discussion pertaining to the Mark IV accelerator upon which this gun is based, see reference [4].
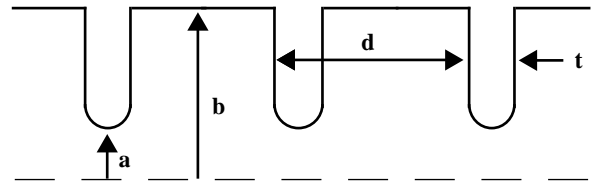

Figure 2: The relevant iris loaded cavity dimensions for the code URMEL. (Iris radius a, cavity radius b, cell length d, iris thickness t.)

A.1 Tuning the gun to 1300 MHz

All the cavity dimensions were machined (fig. 2) according to the URMEL values except b, the cavity's inner radius. Since the iris loaded gun acts like six coupled pill box cavities operating in the TM_{010} mode, we see that the resonant frequency is determined primarily by the pill box's radius, b. Based on this we chose b as our knob for tuning the cavity.

Although the rf will eventually be coupled to the gun through an iris (fig 1) in the coupler cell (CC) we first stacked together seven similar cells (two half cells and five full cells) in order to bring the tune near to 1300 MHz. The code URMEL predicted that the $\pi/2$ mode would be found at 1300 MHz for 2b = 7.153 inches. This prediction turned out to be in excellent agreement with the actual result, it's accuracy was within 0.02% (Δf=0.2MHz). Of course, the consistency of the prediction with the measurement depends on both URMEL's accuracy and the machining accuracy of the local machine shop. The radius, b, was initially cut to 96% of the target radius (b_{URMEL} = 7.153 inch) and consequently, the initial resonant frequency ended up 50 MHz high (f=1350 MHz). The procedure was then to make a sequence of small cuts of the radius b and measurements of the resonant frequency of the $\pi/2$ mode as we approached 1300 MHz slowly. The general agreement of the measurements with URMEL as the gun was tuned was excellent. (fig 3).
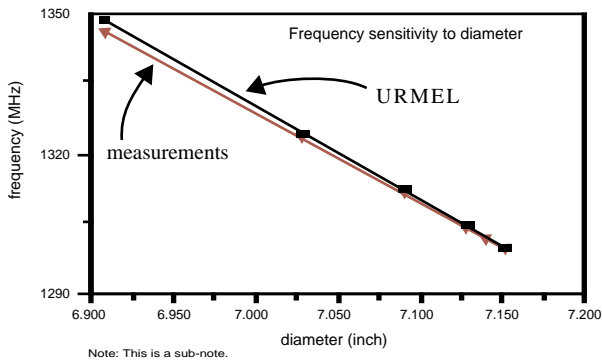

Figure 3: The resonant frequency of the witness gun as a function of the diameter, 2b.

Although the data in figure (3) looks linear ($\Delta f \big/ \Delta(2b) \approx 200\,kHz/mil$) this isn't quite true. The frequency sensitivity, $\Delta f/\Delta b$, varies significantly enough so that it must be taken into account while tuning the gun. The reader should also take caution to realize that this is a very narrow frequency band and just about anything will look linear over such a small interval.

A.2 Matching rf to the gun

The other major issue in the gun's construction is coupling power to the gun or impedance matching. During the initial tuning phase, coupling was achieved with a pin probe on axis. This was sufficient to bring the resonant frequency near the target frequency of 1300 MHz. At this stage, however, we obviously needed to place the actual CC into the gun stack (fig 1). At this point we were operating somewhat blindly (i.e.

without a numerical code) since URMEL cannot model the effect of the coupling iris on the resonant frequency.

Unfortunately, when the cells were stacked together, the Q of the cavity was very low. It was discovered that a significant amount of rf was leaking out through faces where the cells joined. Even with tight clamping of the stack, the measured Q remained around 2000, compared with URMEL's prediction of 13,800. Since S11 measurements are extremely sensitive to these leakage fields we decided to braze two half stacks together. We brazed together the 3 1/2 cell stack on the upstream side of the CC and the 1 1/2 cell stack on the downstream side of the CC (fig. 1).

The brazing of the half stacks had the desired effect and raised the Q to 8000. Although still significantly below the final expected value, this was enough of an improvement to proceed with matching and tuning. Since the effect of the coupling iris is to lower the frequency of the gun, the diameter of the CC was left lower than the diameter of the other five cells.

When the CC was placed into the stack with the two brazed sections, the frequency of the entire stack measured about 4 MHz high. We then began an iterative process of opening the iris and cutting the radius, b, of the CC while carefully measuring the resonant frequency and reflection coefficient S11. Unlike the initial tuning of the stack with 6 similar cells, this stack's frequency and coupling had a highly nonlinear dependence on the diameter and the coupling slot dimensions. Far from 1300 MHz, the cavity's tune was not very sensitive ($\Delta f/\Delta 2b$ = 8 kHz/mil) to changes of the radius b. But when the cavity was back to within 0.5 MHz of 1300 MHz, the resonant frequency became extremely sensitive ($\Delta f/\Delta 2b$ = 90 kHz/mil) to changes in b.

Since there were still two unbrazed joints in the stack, there continued to be problems in obtaining reliable measurements of S11. The reflection coefficient lied in the band between -5dB and -15dB at a slot length and width of 2 and 1/2 inches respectively. Since it would have been very easy to over couple the cavity by opening the slot further, we decided to send the gun out for it's final braze. The final adjustment of the iris will be done after the complete cavity is brazed together.

B Pre-Braze Results

The first task was to identify the seven TM_{010} like modes of the six cell cavity. When the stack was put together with all similar cells instead of the CC, all seven modes were easily identified. However, when the CC was in the stack, we only observed six modes (fig 4). It is likely that the $5\pi/6$ and the π modes have become degenerate, since all modes are live in the CC and therefore should be driven. The ultimate resolution of this will come when the cavity arrives back at ANL so we can do a bead pull to identify the modes. Summary of the modes

mode	0	$\pi/6$	$\pi/3$	$\pi/2$	$2\pi/3$	???
freq	1284.3	1286.9	1293.0	1299.3	1207.0	1313.9

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S11        log MAG
REF -5.0 dB
1   1.0 dB/
▽  -6.4358 dB
hp

MARKER 1
   1.2992 GHz

1→
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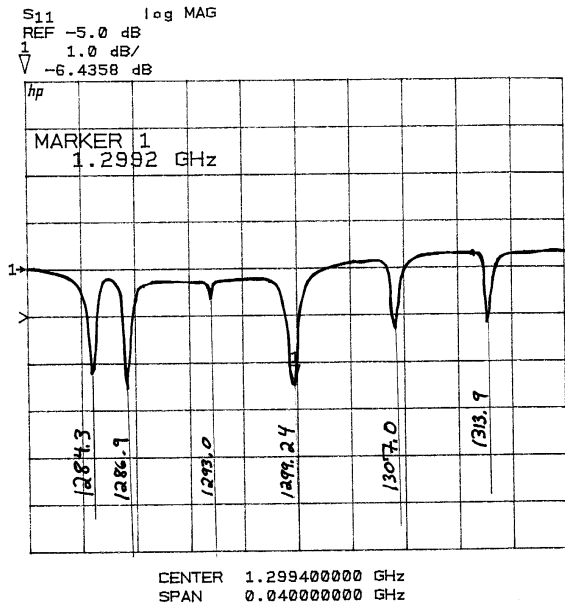
Figure 4: Six of the Seven TM_{010} like modes of the witness gun

III. DIELECTRIC GUN

The dielectric gun [1] option for the witness beam has been put on the back burner for the time being. Since Phase I of the AWA project needed a reliable witness beam quickly, it was decided that the development of the dielectric gun would be to great of an undertaking. Briefly, the dielectric photocathode gun consists of a dielectric tube (1 cm ID x 5.44 cm OD x 32.57 cm length) inserted into a copper jacket. The central advantage of this gun is that the rf fields of the gun are almost completely linear and may produce a lower emittance beam. The authors of this paper still consider this a worthwhile endeavor.

IV. FUTURE PLANS

As of this writing, all components of the witness gun are being brazed together. The first order of business upon arrival of the gun will be to complete the tuning and matching of the gun. After some cold test on the gun we plan to mount the gun in place and begin conditioning. We plan to see the first laser pulse strike the photocathode in June. This event will mark the beginning of an exciting era of research to take place at the AWA.

V. REFERENCES

[1] J. Power et. al., "Witness Gun for the Argonne Wakefield Accelerator", Proc. 1992 Particle Accelerator Conference.
[2] P. Schoessow et. al., "The Argonne Wakefield Accelerator: Overview and Status" (same as reference [1])
[3] W. Gai, et. al.., "Experimental Demonstration of Wake-Field Effects in Dielectric Structures" Phys. Re. Lett., **61**, 2756 (1988)
[4] The Stanford Two-Mile Accelerator, (Chpt. 6)

Although the gun hadn't been completely brazed together at the time of this writing, a bead pull was performed on the $\pi/2$ mode (fig 5). The experiment (performed on HP 8510 Network Analyzer) clearly identifies the mode as $\pi/2$. The CC is located approximately between 200 and 250 mm in figure 5, which explains the odd shape in that region. The last "hump" in the plot doesn't come up to full field balance due in part to the leaky rf joint of the CC. The last hump will probably not come all the way up to full field balance even after brazing since that is the side on which the beam exit hole resides. The fields that exist after the dashed line of figure 5 are the fields that attenuate in the beam exit hole.
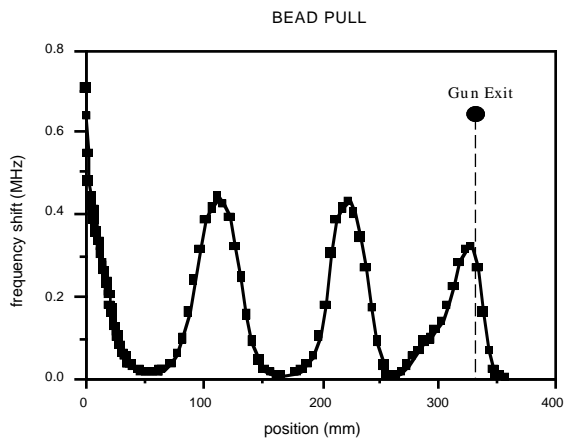

Figure 5: Bead pull showing the $\pi/2$ mode in the witness gun