CONSTRUCTION OF THE ALPHA-X PHOTO-INJECTOR CAVITY*

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Abstract

We will describe the construction and low power testing of an RF cavity to be used as a photo-injector for the ALPHA-X project within the Department of Physics at the University of Strathclyde (UK). The gun is a two and a half cell S-band cavity, employing a metallic photo-cathode. RF power is coupled to the gun via a co-axial power coupler. The specification of the gun and the low power measurements made to achieve the correct mode frequency and field flatness will be presented.

INTRODUCTION

Laser-driven plasma accelerators will require ultra-short electron bunches (< 100 fs) due to the short wavelengths of the accelerating medium. Although such bunches may one day be provided by "all-optical" injection techniques, some projects will use radio-frequency cavities as photo-injectors. The "**A**dvanced **L**aser-**P**lasma **H**igh-energy **A**ccelerator towards **X**-rays" (ALPHA-X) project at the University of Strathclyde in Glasgow will investigate both injection methods [1]. The photo-injector for ALPHA-X is designed to produce a ~ 6 MeV beam of 100 pC with a normalised emittance of 1 mm-mrad from a 2½ cell, standing wave, S-band cavity operating in the familiar π mode. The cavity RF specifications are shown in Table 1. The operating frequency is for the cavity under vacuum and within a temperature range from 30 ℃ to 45 ℃.

Table 1: Cavity specifications

frequency	2,998.550 MHz
VSWR	< 1.1
Field flatness	< 15%

CAVITY DESCRIPTION

The cavity design is based on one previously used at the Eindhoven University of Technology [2] which, in turn, was based on a Brookhaven National Laboratory design [3]. The theoretical dimensions of the cavity were calculated, using the SUPERFISH code, and a schematic is shown in Fig. 1. An important difference with respect to the first Eindhoven cavity is the use of "elliptically" shaped irises rather than the "circular" BNL shaped ones (Fig. 2). This allows the achievement a smaller peak electric field on the iris for a given axial accelerating field (0.9 for elliptic cells as opposed to 1 for cylindrical cells),

which will help to reduce dark current levels. As the production of a low emittance beam favours a cylindrically symmetric cavity the RF power is coupled to the gun via a co-axial "doorknob" antenna similar to that used for the L-band gun of the Photo-Injector Test facility in Zeuthen [4].
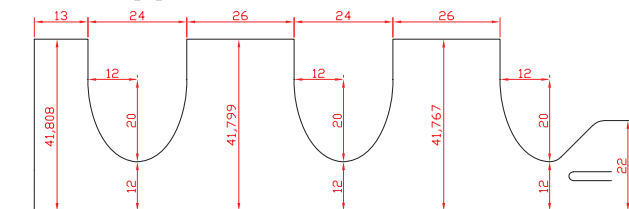

Figure 1: Schematic of the RF gun.

The cavity and its power coupler are machined from OFHC copper. The "cathode" is merely a copper plate in the first (half) cell. Thus, the gun employs a metallic photo-emitter. The relatively poor quantum efficiency of copper ($\sim 10^{-5} - 10^{-4}$) is not a problem as the ALPHA-X facility has ample laser energy to extract the charge required. In order to be de-mountable, the cathode plane is brazed to a stainless steel flange which is screwed to the flange of the half-cell of the gun.
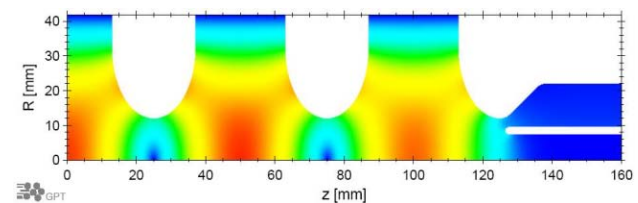

Figure 2: False colour image of the cavity electric field.

The need for cylindrical symmetry precludes the use of tuning "plungers" for adjusting the frequency of the cavity. The Eindhoven gun was machined to within 1 micron of the theoretical dimensions in order to obtain the desired resonant frequency. At Orsay, the available machining accuracy was limited to 20 μm. It is easy to show that a 20 μm error on the iris cell diameters would result in a large frequency error (~ –35 kHz/μm). Given the limit in machining accuracy, our approach to reaching the correct frequency was the following; the cell diameters were initially machined to be 100 μm smaller than their nominal values, thus allowing us to approach the correct dimensions in an iterative fashion. Low power measurements of the cavity frequency between successive machining operations and the frequency sensitivity to cell radius (given by SUPERFISH calculations) enabled us to estimate the amount of material to remove on each iteration. The low power measurements are made at

ambient pressure, whereas the gun will operate under vacuum. This results in a calculable shift in the mode frequency (~ 900 kHz) which must be allowed for. Brazing of the cells can produce an additional, unpredictable, frequency shift. Previous experience has shown that this increases the frequency (the increase finally observed was 220 kHz). Therefore we initially aimed for a lower value (~ 2998.15 MHz at 20 ℃) anticipating that the final adjustment of the operating frequency could be achieved by regulation of the operating temperature around the intended nominal value of 30 ℃ via the cooling system (~ –50 kHz/degree). The cooling system of the gun was designed to allow operation in the range of 30 ℃ to 45 ℃. Alternatively "dimple" tuning can be used to provide some variation in the operating frequency. Indeed this was foreseen from the beginning. Holes were machined from the exterior of the cells, in their horizontal mid-plane, to allow a tool to perform the deformation. This technique, nevertheless, reduces the cylindrical symmetry, albeit very slightly. An image of the three cells and the input coupler, prior to brazing is shown in Fig. 3.

Figure 3: Cavity cells and input coupler prior to brazing.

Prior to brazing, the three cells, a "dummy" cathode plate and the coupler were clamped together to measure the frequency and field flatness by "bead-pull" perturbation techniques. The π mode frequency was at 2,998.200 MHz and the un-loaded quality factor, Q_0, was 10,900. The field flatness was better than 3% (Fig. 4).

Before brazing, the cells received an acid cleaning which, unfortunately, proved to be too aggressive (> 20 μm were removed) resulting in a frequency drop of 860 kHz. It was decided to braze the cells and to correct the frequency by dimple tuning. In order to limit the required deformations of the cells, four additional holes were machined in each cell making 6 holes/cell at 60 degree intervals. Manually driven screws are used to perform the deformation. Contact with the external surface of the cavity is made via a stainless steel ball in order to avoid rupture of the metal. We estimate that the maximum deformation applied is of the order of 0.2 mm.
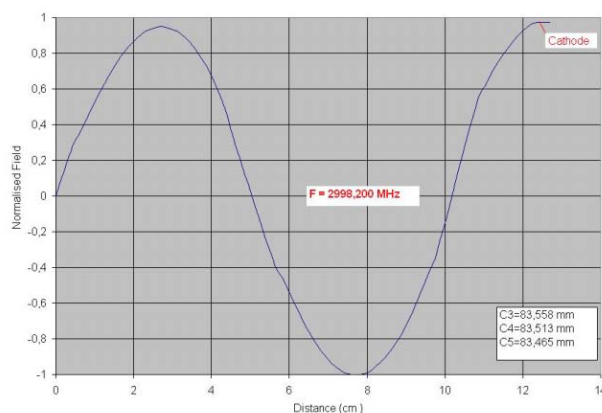

Figure 4: Measured field distribution along the cavity.

The Input Coupler

The input coupler is a hollow co-axial line of 50 Ω impedance which couples to the output cell of the gun. The input waveguide is terminated in a short circuit suitably positioned in order to provide a correct RF match to the cavity. This waveguide has twelve 3 mm wide slots, separated by 5mm, machined in both its narrow walls through which the cavity is pumped via a cylindrical chamber TIG welded to a ring which, in turn, is brazed onto the waveguide. In order to verify the parameters of the coupler it was necessary to build conical "tapered" transitions to adapt the coupler dimensions to those of our standard 7/16" connectors. These transitions allowed the optimisation of the position of the short circuit mentioned above. By varying the position of the short circuit a return loss for the coupler of better than 40 dB into a matched load was obtained (Fig. 5).
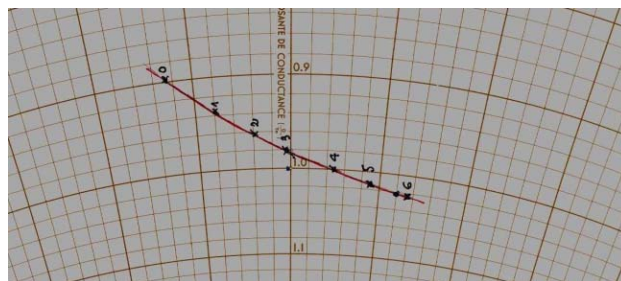

Figure 5: Smith chart display of the VSWR of the coupler vs. short circuit position.

After determination of its correct position, the short circuit, the waveguide, the input flange (LEP Injection Linac type) and the ring for the vacuum chamber were brazed using a silver-copper eutectic (PALCUSIL 5, ~ 880 ℃). The connection of the gun to the coupler is made through a special annealed gasket. Initially the coupler antenna is over-coupled to the cavity by starting with an antenna which is deliberately too long. Successive machining of the antenna, to reduce its length, resulted in a VSWR of 1.03 for an antenna to output-iris distance which agreed with the calculated distance to within 0.1 mm. Finally, the antenna, along with its input and output

CF63 flanges were brazed to the input waveguide using eutectic 780 EL-190 braze material. The complete brazed coupler is shown in Fig. 6.
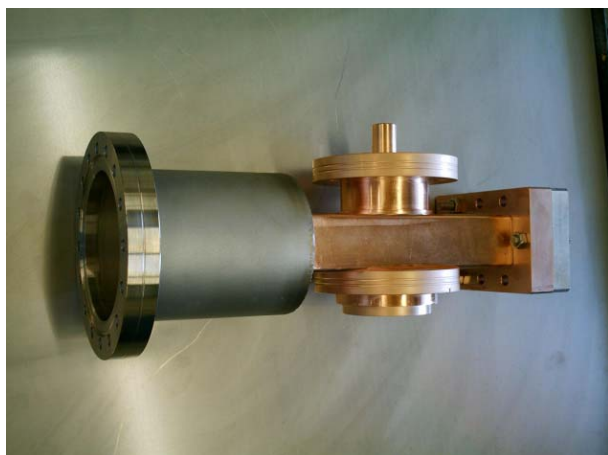

Figure 6: The coupler after brazing.

RESULTS

The final completed cavity is shown in Fig. 7. By measuring the transmitted RF signal while performing perturbation measurements one can determine the field profile and, by applying the Dekleva-Robinson formula [5], we can measure the cavity shunt impedance, R_s, (uncorrected for the transit-time effect). This technique gives $R_s = V^2/2P_c$ (where V is the accelerating voltage and P_c is the dissipated cavity power) = 2.88 MΩ or $R_s/Q_0 = 264\ \Omega$ to be compared with 271 Ω as calculated using SUPERFISH. The final VSWR of the coupler-cavity arrangement is 1.04. The π mode frequency, in air and at 20 °C, is 2998.240 MHz which means that one can estimate that it will be necessary to operate, under vacuum, at ~ 32 °C to reach the desired frequency.

Figure 7: The completed ALPHA-X photo-injector.

CONCLUSIONS AND REMARKS

The RF cavity for the ALPHA-X project has been built and tested at low power. The measurements show that the cavity meets the required specifications. The cavity was shipped to Glasgow in October of 2005. At the time of writing it is currently installed on the ALPHA-X beam-line and is awaiting high power RF conditioning. A second cavity is under construction on which we aim to minimise the use of dimple tuning. This gun would be used as a "spare" injector. It would also incorporate a concave bevel on the axis of the photo-cathode for the production of short bunch-length electron beams [6].

ACKNOWLEDGMENTS

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