# INITIAL RF TESTS OF THE DIAMOND S-BAND PHOTOCATHODE GUN

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*Abstract*

An S-band photocathode electron gun designed to operate at repetition rates up to 1 kHz CW has been designed at Diamond and manufactured at FMB. The first test results of this gun are presented. Low-power RF measurements have been carried out to verify the RF design of the gun, and high-power conditioning and RF test has begun. Initial high power tests have been carried out at 5 Hz repetition rate using the S-band RF plant normally used to power the Diamond linac: the benefits and limitations of this approach are considered, together with plans for further testing.

## GUN DESIGN

In recent years, the RF photoinjector gun has been increasingly used as a source of high brightness beams for free electron lasers [1, 2], inverse Compton scattering sources [3] and ultrafast relativistic electron diffraction devices [4]. A programme is underway at Diamond Light Source to develop a high repetition rate S-band photocathode gun [5] using a coaxial RF coupler similar to that used at the DESY PITZ gun [6]. Such an approach preserves the axial symmetry of the gun, ensures coupling takes place in a region of low power dissipation and allows the gun main solenoid to be mounted directly around the gun cavity to achieve minimum transverse emittance [7]. The DLS gun is a 1.6-cell design with a removable cathode plug. The RF electric field distribution of the accelerating π mode is shown in Figure 1: the cathode plug is located at the lower left and the coupler is on the right.

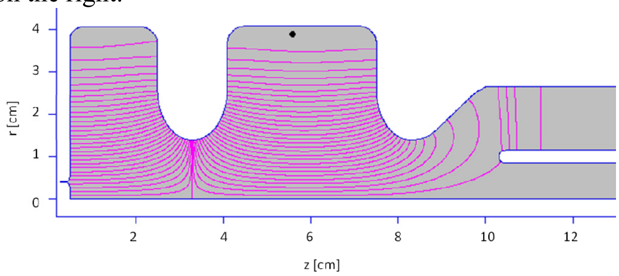


Figure 1: SUPERFISH calculation of π mode

The gun was manufactured at FMB and delivered to Diamond in early 2012: Figure 2 shows the assembled gun and coupler. Gun cavity and coupler are two brazed units connected by a Conflat fitting using one of a range of spacer gaskets of different thickness used to control coupling. The gun includes extensive water cooling channels allowing it to operate at a pulse repetition rate of 1 kHz, and to enable fine tuning of the cavity resonant frequency by control of the water temperature.

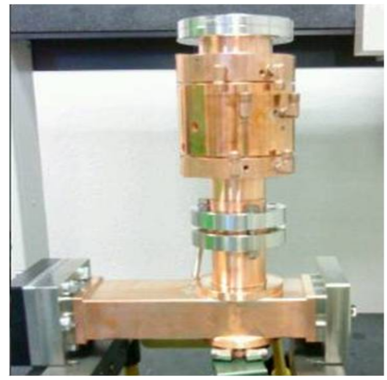

Figure 2: The assembled gun and coupler

## LOW POWER TESTS PRIOR TO TUNING

Gun and coupler were probed together at Diamond using a Rohde and Schwarz ZB8 Vector Network Analyzer. Three resonances were measured around 3 GHz: the zero mode (2984 MHz), π mode (3003 MHz) and a small mode at 3021 MHz located at the antenna. The frequency of the π mode at room temperature was designed to be higher than the operating frequency of 2998 MHz in order to compensate for the drop in frequency expected as the cavity warms to its operating temperature when RF power is applied.

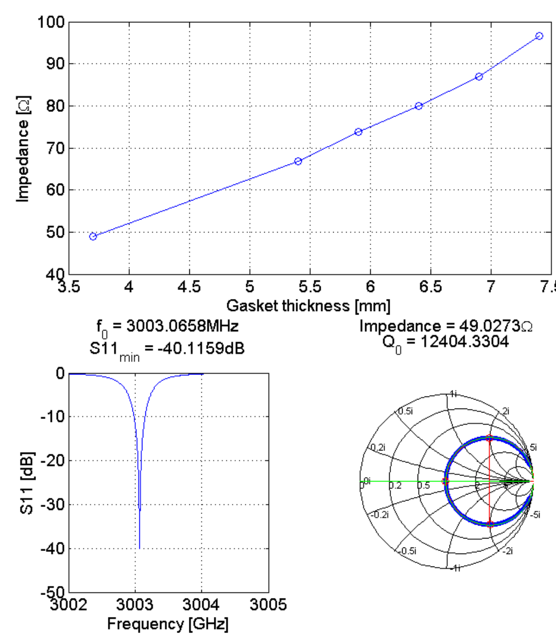


Figure 3: Tuning of gasket thickness for critical coupling (above) and cold test results at critical coupling (below).

A number of coupling gaskets were tested to establish critical coupling. Results are shown in Figure 3, with the full range in the upper plot and the cavity parameters with critical coupling displayed in the lower plot.

A set of cathode pieces were manufactured with holes drilled through their centres to allow a bead-pull measurement to be carried out. In this measurement, the cavity was mounted vertically and a dielectric bead was pulled along the axis while the resonant frequency was monitored with the VNA. For a small spherical bead of radius $r$, the electric field, $E$, at the point of the bead can be related to the measured relative frequency shift, $\Delta f/f$ by

$$\left(\frac{\Delta f}{f}\right) = -\left(\frac{\pi r^3}{U}\right)\left[\varepsilon_0\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right)E^2 + \mu_0\left(\frac{\mu_r - 1}{\mu_r + 2}\right)H^2\right]$$

where $\varepsilon_r$ is the relative permittivity of the bead. For a dielectric bead with permeability $\mu_r = 1$, the frequency shift is independent of magnetic field and the measured change in frequency can be used to measure the electric field at a point in the cavity.

Results of a bead pull measurement for the cavity as manufactured with no fine tuning are shown in Figure 4. The peak field of the first (half) cell was found to be 17% greater than the peak field of the second (full) cell.

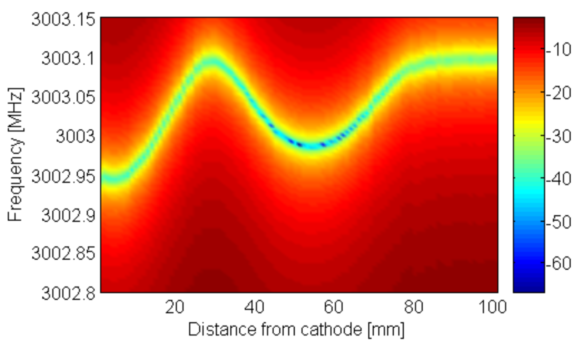


Figure 4: Bead pull results before correction

After evacuation of the cavity, vacuum bake-out tapes were used to control the cavity temperature and investigate the drop in resonant frequency caused by thermal expansion. Resonant frequency rose by approximately 1 MHz on evacuation. The plot in Figure 5 shows that some further tuning was necessary to bring the cavity frequency down to the level such that water temperature control could be used for fine tuning around 2998 MHz.

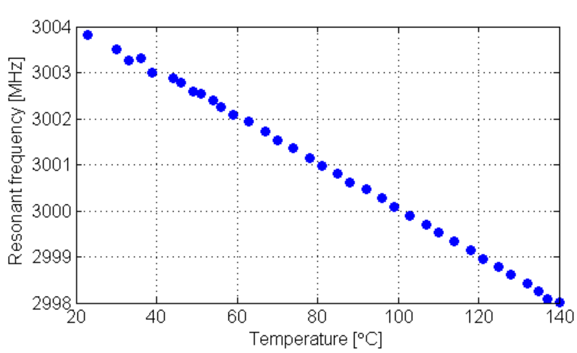


Figure 5: Scaling of resonant frequency with temperature before correction.

## TUNING BY CATHODE INSERTION

The only component that is readily accessible for a rework is the cathode, as it is designed to be easily removed and replaced. Tuning by cathode position preserves the axial symmetry of the gun and is completely reversible, requiring no plastic deformation of the cavity walls. Moving the cathode surface info the first (half) cell has the effect of reducing both the resonant frequency and the field imbalance, as shown by the SUPERFISH calculations in Figure 6. $Q_0$ of the cavity is also increased by approximately 1000 with a 2 mm re-entrant cathode.

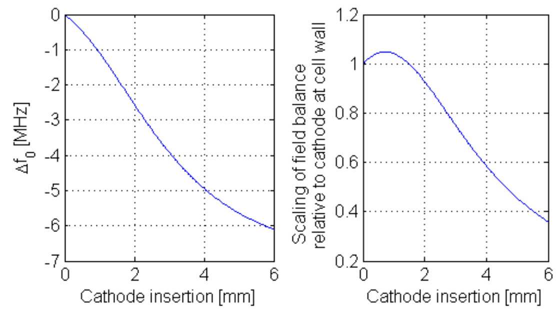


Figure 6: Prediction of cathode tuning

Five new cathode pieces were made up to investigate this approach, with results summarised in Figure 7 and Figure 8, for measurements in air.

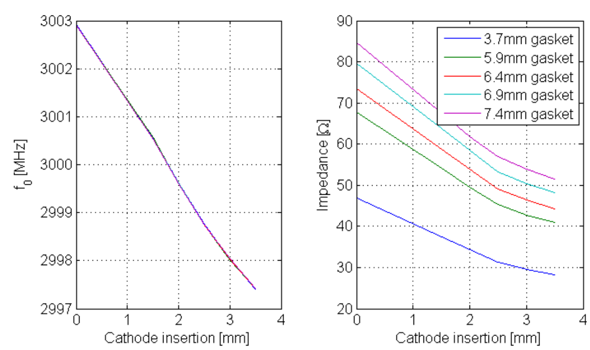


Figure 7: Change of resonant frequency (left) and impedance (right) with re-entrant cathode.

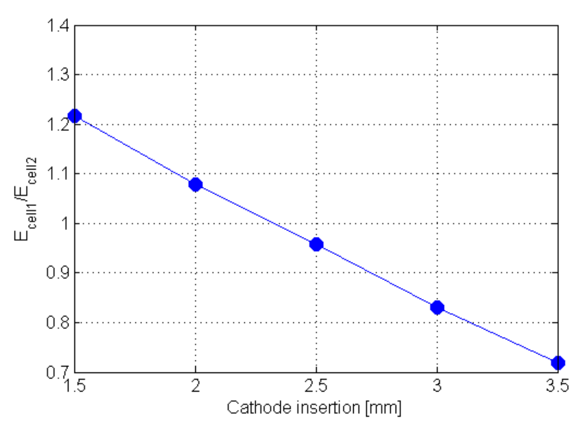


Figure 8: Field balance measurements with re-entrant cathodes.


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The original design parameters for the gun were a field excess of 4% in the first cell and a resonant frequency of 2998 MHz at an elevated temperature achieved by RF heating and precisely maintained by the water in the cooling channels [5]; tuning of the gun by adjustment of the cathode face positioning has allowed these parameters to be achieved.

## HIGH POWER TESTS

RF parameters of the evacuated gun at 20°C after correction by cathode adjustment and choice of appropriate coupling gasket are shown in Figure 9. This gun was mounted on a test bench for high-power RF testing. Prior to the test, the gun was pumped down for four weeks to 5 x $10^{-9}$ mbar.

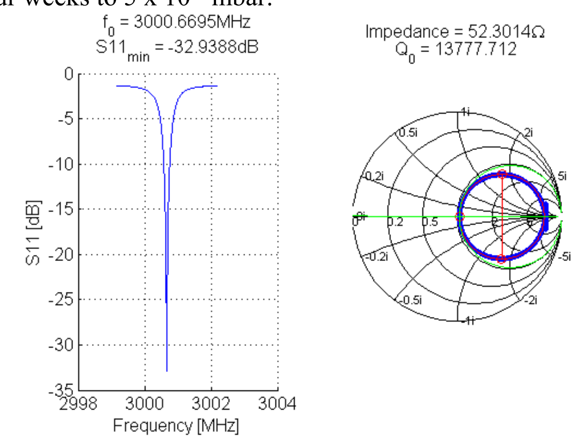


Figure 9: Characterisation of gun with re-entrant cathode

A photograph of the high-power test bench is shown in Figure 10: the gun is wrapped in bake-out foil in this picture. Power is supplied from one of the DLS linac amplifiers, which can provide pulses well in excess of the 3 µs, 6 MW requirement of the gun, although only at a repetition rate of 5 Hz. The bench is connected to a recently installed switch in the waveguide network [8] through a Titan Beta air-cooled circulator and forward and reflected power are monitored with a directional coupler close to the gun window. The waveguide is pressurised to 2 barG with $SF_6$.

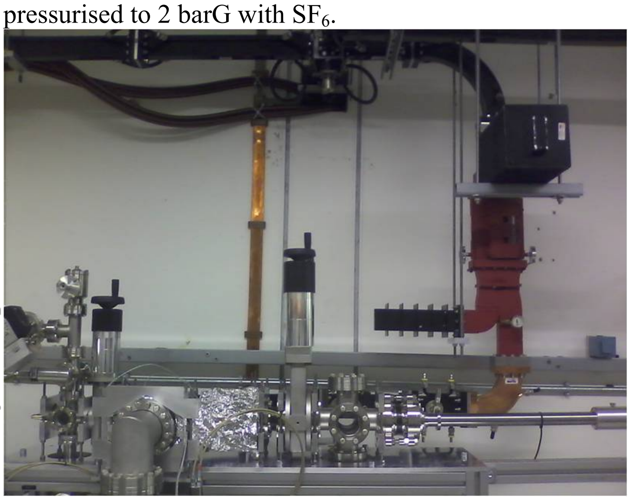

Figure 10: Gun assembly for high-power tests

Initial high-power test results are encouraging: Figure 11 is a record of the first period of conditioning of the corrected gun, showing forward power in the top plot and vacuum activity in the lower plot. A 3 µs RF pulse was used, and the gun conditioned rapidly allowing 2 MW to be applied to the gun within two working days. Initial vacuum activity died away quickly, and towards the end of the conditioning period the conditioning events were all arcs recorded by the arc detector viewing the window.

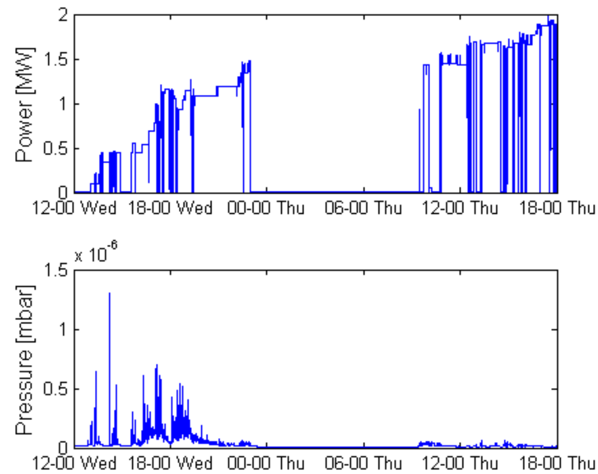


Figure 11: S-band gun conditioning

## CONCLUSIONS AND FURTHER WORK

An S-band photoinjector gun has been manufactured and delivered to Diamond Light Source and low-power RF characterisation has been carried out. Reversible frequency and field flatness tuning has been achieved by adjusting the position of the cathode surface, and high power conditioning has begun. The effect on beam of the RF field distortion introduced by the cathode shift must be studied in detail, and work is underway to design and build the solenoid coils required for gun operation. A second gun cavity is also in design that requires a smaller RF correction to reach the target parameters.


## ACKNOWLEDGEMENTS

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