LOW POWER RF CHARACTERISATION OF THE 400 Hz PHOTOINJECTOR FOR CLARA

L. S. Cowie*[1], B. L. Militsyn, P. Goudket, T. J. Jones[1], STFC Daresbury Laboratory, Daresbury, UK
G. Burt, Lancaster University, Lancaster, UK
[1]also at Cockcroft Institute, Lancaster University, UK

Abstract

The CLARA High Repetition Rate Photoinjector comprises an S-band dual feed cavity and will operate at 2.9985 GHz at a repetition rate of up to 400 Hz. It is capable of reaching an electric field strength on the cathode of 120 MV/m. The cavity was brazed after tuning and arrived at Daresbury Laboratory in February 2016. Extensive low power RF testing has been performed including measurements of the quality factors and coupling, pass-band mode frequencies, on axis field and RF repeatability of replacement of cathode plug. The dual feed coupler has been tuned and a Magic Tee type splitter installed. The photoinjector is now installed on the VELA beam line for commissioning and characterisation.

INTRODUCTION

CLARA is a new FEL test facility being developed at STFC Daresbury Laboratory in the UK [1]. The CLARA High Repetition Rate Photoinjector, shown in Fig. 1 will operate at a repetition rate of up to 400 Hz and is capable of reaching an electric field strength on the cathode of 120 MV/m [2]. The cavity has a dual feed coaxial coupler and a measurement probe at the equator of the second cell. The cavity was designed at Daresbury and manufactured and tuned at Research Instruments [3] [4]. The cavity has a load lock cathode system that enables 10 mm cathode plugs, held with an RF spring, to be removed and replaced under vacuum.

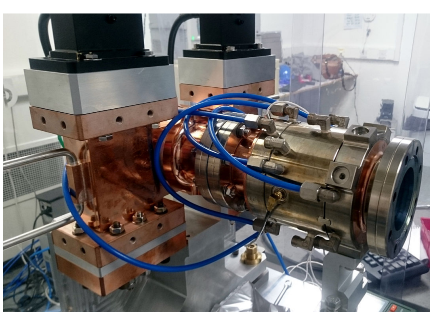

Figure 1: 400 Hz photoinjector on the bead-pull test stand at Daresbury Laboratory.

LABORATORY MEASUREMENTS

Resonant Frequency

The resonant frequency of the operating mode, the resonant frequency of the other passband mode, and the coupling characteristics of the cavity as delivered were measured using the same methods detailed in [3].

The cavity was measured with a copper cathode and a copper RF spring, and later with one of 6 molybdenum cathodes that will be used for RF conditioning and a gold coated RF spring. The cathodes were held in place by a steel plate bolted to the back of the cavity. The measurements scaled to vacuum conditions are shown in Table 1. The measured reflection coefficient Γ from the cavity is shown in Fig. 2. The cavity is on tune and the mode separation is sufficient to avoid beating between the modes [5].

Table 1: RF Parameters with Each Cathode

	Cu cathode and Cu spring	Mo cathode and Au spring
f (MHz)	2998.49 ± 31 kHz	2998.56 ± 17 kHz
β	0.97 ± 0.05	1.071 ± 0.008
Q_0	12508 ± 400	13167 ± 52
Q_L	6365 ± 100	6356 ± 10

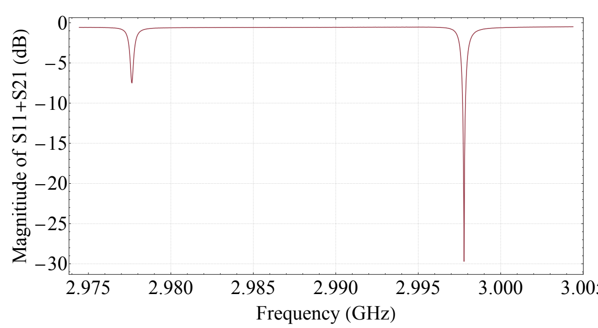

Figure 2: Measured reflection coefficient calculated from the S-parameters at both input ports at $\frac{1}{3}$ psi positive nitrogen pressure at 50 °C.

Measurement of on Axis Fields

The field on axis was measured using the perturbation measurement technique and image charge compensation described in [3], and the copper cathode with 0.5 mm hole in the centre for the beadpull string. The result is shown in Fig. 3. The field flatness of the structure was 98 ± 1 %.

CATHODE REPLACEMENT

RF Measurement

Repeatability tests were performed with all cathodes. This was to quantify the repeatability of the RF cavity proper-

* louise.cowie@stfc.ac.uk

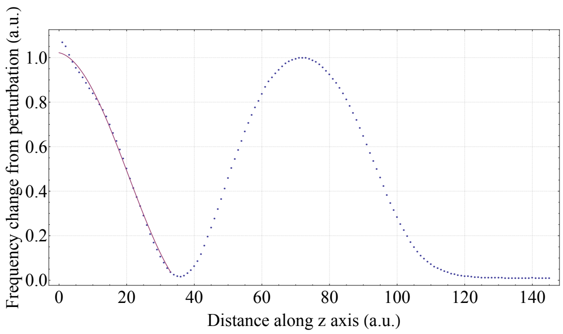

Figure 3: Bead-pull measurement of on axis field

ties when removing and replacing the same cathode. The cathodes tested were the copper bead-pull cathode and 6 molybdenum cathodes. The tests were performed with a plain copper RF spring, and later with a gold coated spring with rhodium interstitial. The repeatability was quantised by calculating the standard deviation from the mean of frequency and β for each cathode. For the copper spring repeatability was poor, but improved with the introduction of the gold-coated spring. The mean standard deviation across all cathodes on frequency was 21.82 kHz wih the copper spring, decreasing to 3.02 kHz with the gold-coated spring. The mean standard deviation on β was 0.041 with the copper spring, decreasing to 0.011 with the gold-coated spring.

The RF properties of the cavity were different with each cathode. The variation was quantised by calculating the standard deviation on the average frequency measured for each cathode. This is 18.5 kHz for the copper spring. For the same spring the standard deviation of the average beta for each cathode is 0.070. The average β for the copper cathode is higher than the molybdenum cathodes. The standard deviation of the molybdenum cathode βs only is 0.029. For the gold-coated spring the standard deviation of the frequencies across all cathodes decreases to 6.9 kHz and βs decreases to 0.021, for the molybdenum cathodes the standard deviation is 0.007.

Dimensional Metrology

The differences in measured RF parameters for different cathodes prompted an investigation into the dimensions of the cathodes. Each cathode was measured with a Coordinate Measuring Machine (CMM) and a shadowgraph to determine the dimensions of several key parameters.

Correlations were calculated between the cathode dimension changes and RF measurements. This was performed first with the plain copper spring. No strong correlation was seen between cathode length and frequency. A strong correlation, Pearson coefficient 0.983, was seen between β and diameter for the molybdenum cathodes. The copper cathode does not fit this correlation as well. This indicates a poor RF contact between the molybdenum cathodes and the spring, which is improved for larger diameter cathodes. The contact, and therefore the β is much higher for the copper cathode. This was confirmed by measuring the field leakage behind the cathode with an antenna. The transmission to the antenna was around -70 ±20 dB with the molybdenum cathodes with the plain copper spring. There was no measurable field leakage with the copper cathode. With the gold coated spring there was no measurable leakage for all cathodes. The Pearson coefficient for the correlation between cathode diameter and beta is decreased to 0.75 for the molybdenum cathodes. The gold coated spring increases the RF contact and prevents leakage. No other significant correlations were seen.

ONLINE MEASUREMENTS

First Online Measurement

The cavity was installed on the VELA beamline and measured with a molybdenum cathode held in place with the same steel plate. The cavity was at air and was heated to 50 °C with water. The operating frequency was measured as 2998.53 ± 0.1 MHz The large uncertainty is due to the unknown humidity in the cavity. The β measured 1.07 ± 0.03.

H-coupler Tuning

The H-shaped dual feed input coupler is designed to avoid a dipole component in the coupler. A simulation was performed in CST MWS [6] to establish the effect of a phase offset in the two feeds of between 0 and 20 mm (0 to 130°). As discussed in [3] the reflection coefficient Γ for a three-port system can be calculated from $S11 + S21$ and equivalently from $S22 + S12$ where ports 1 and 2 are the symmetrical phase-matched input ports [7]. Figures 4 and 5 show how $S11 + S21$ and $S22 + S12$ vary as the input phase to port 1 is varied in simulation in CST MWS [6].

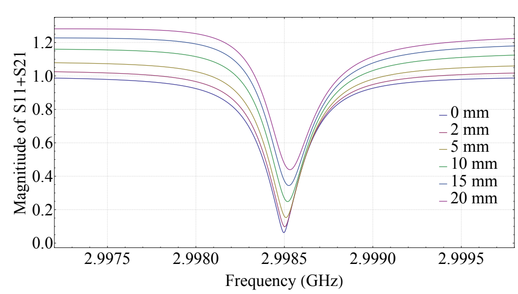

Figure 4: Simulation of S11 + S21 from the cavity to each port as port 1 input phase is varied.

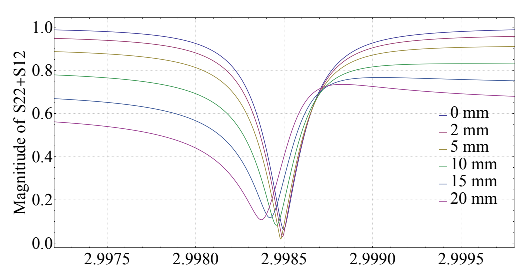

Figure 5: Simulation of S22 + S12 from the cavity to each port as port 1 input phase is varied.

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A dipole component at the coupler iris was produced by a phase offset. 3D fields for the 1 mm and 10 mm cases were imported into GPT [8] to assess the affect on the beam in CLARA. It was concluded that for the 1 mm case although there was a transverse beam offset it was damped by the end of the linac. The same effects were seen for the 10 mm case but was maintained along the beam line.

The tuning range of the coupler is ±0.5 mm on each flexure tuner, giving a path length change of ±1 mm per tuner. A Magic Tee will be used to split the incoming RF between the two ports. The phase difference between the two output ports of the Magic Tee was measured to be 0.89° ± 0.08. This is low enough to have a negligible effect on the beam and as such no correction was applied. The H coupler was tuned using the flexure tuners, the tuning result is shown in Figure 6.

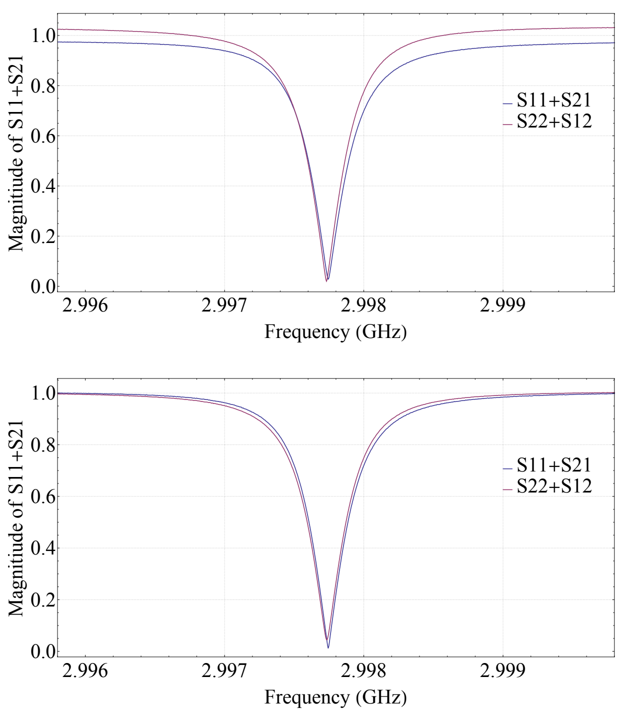

Figure 6: Reflection measurement before and after retuning.

Load Lock Cathode System

The cavity was measured with the cathode held in place by the load lock system. Repeatability tests were performed for removing and replacing the cathode and whilst the frequency was very repeatable, down to 10s of kHz, there was some variation in the measured beta. The load lock system uses a magnet to move a transfer arm holding the cathode to load the cathode into the cavity. This magnet can be used to exert force on the back of the cathode and hold it in place or it can be left free. The standard deviation on the measurement of β was 0.026 without any force and 0.0048 with force applied. The stop on the arm has been placed in the optimal position and the magnet should be held in place against the stop. A sprung mechanism has been designed for this purpose, which includes interlocked switches to confirm the arm is in place.

Final Installation and Bake

The Magic Tee was installed, and then the pumping port and the vacuum window. The cavity was measured at each stage and all RF characteristics were as expected. The cavity was baked at 150 °C for 72 hours. After the bake the frequency at vacuum and 48.8 °C was 2998.554 MHz, suggesting a required running temperature of 49.8 °C. The β was 1.077 and the mode separation was 20.07 MHz. The reflection coefficient and transmission to the probe are shown in Figure 7.

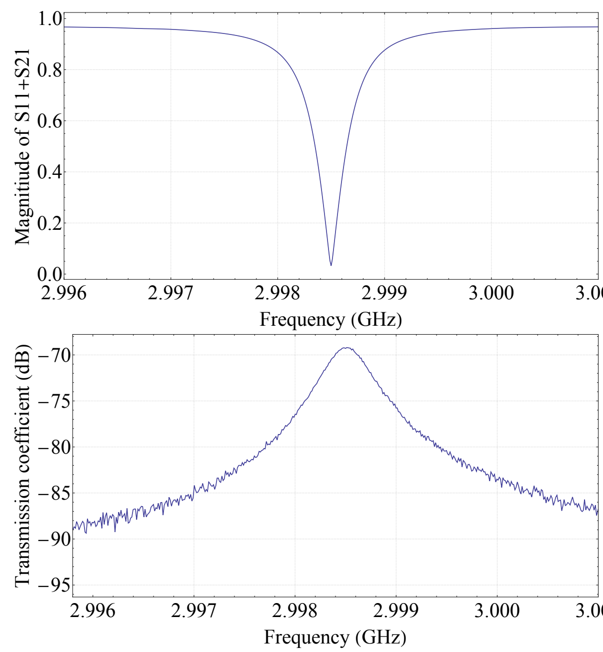

Figure 7: Reflection and transmission coefficients

CONCLUSION AND FURTHER WORK

The CLARA 400 Hz cavity was fully characterised at low power. The frequency, Q and field-flatness are all within design tolerance. The coupler was tuned and the cavity is on the VELA beamline ready for RF conditioning and beam commissioning and characterisation.

ACKNOWLEDGEMENTS

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