VELA PHOTOINJECTOR CAVITY RF INVESTIGATIONS

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Abstract

One of two ALPHA-X photocathode gun cavities, designed and fabricated at the Laboratoire de l'Accélérateur Linéaire, has been in operation on the VELA electron accelerator at Daresbury Laboratory since first beam in April 2013. In this time the maximum beam momentum recorded is 5.06 MeV/c. An investigation of the cavity has been performed with the aim of reconciling the expected momentum of over 6 MeV/c with the measured momentum. RF and beam simulation results are presented along with low power RF measurements of the cavity. One source of momentum loss, the flatness of the cathode face, is identified and rectified.

INTRODUCTION

The VELA facility [1-4] consists of a 2.5 cell normal conducting S-band RF photoinjector [5] with a coaxial coupler, which provides an electron beam to experiments in the accelerator area and 2 user areas. The removable copper cathode is the entire back wall of the cavity and is brazed to a stainless steel flange. RF contact with the cavity side wall is achieved through bolting the cathode to the cavity bulk with 6 bolts, pressing the cathode face on to the end of the side wall. A schematic of the photoinjector assembly can be seen in Fig. 1.

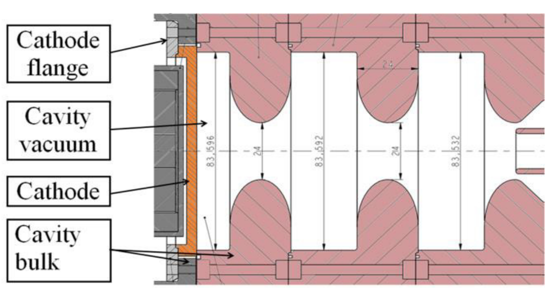

Figure 1: Assembly for the VELA photoinjector.

Since the beginning of operations VELA has achieved a maximum momentum of 5.06 MeV/c. Previous approximate calculations of the final momentum predicted 6.16 MeV/c at the same RF power. It was therefore decided to perform simulations and low power RF cavity testing to explain the discrepancy, and if possible rectify it. In this paper we investigate geometrical effects, but there is also a resonant mode nearby to the operating mode that will be the subject of future work.

SIMULATED EFFECT OF CAVITY GEOMETRY ON BEAM MOMENTUM

The cavity was modelled first in CST Microwave Studio (MWS) [6] to determine the axial field profile and the ratio of E_{peak}^2/P where E_{peak} is the peak axial electric field and P is the forward power. E_{peak} can then be scaled to a constant power and entered into an ASTRA [7] beam tracking simulation along with the field profile. All ASTRA simulations are at crest phase. A value of 8 MW was chosen for the simulations as this power can consistently be reached during operation. For a cavity with the same absolute peak E field in each cell the momentum predicted from simulation is 6.09 MeV/c.

To establish the effect geometrical adjustments to the cavity could have on the beam momentum, this process was repeated for cavities with variations from the nominal dimensions. Three types of variation were studied:

- Each of the three cell radii were varied up to ±10 µm from nominal.
- The longitudinal cathode position was varied up to ±30 µm from nominal.
- A gap between the cavity wall and the cathode was modelled up to 300 µm.

The results of the simulations are shown in Figure 2. There are two mechanisms that cause the difference in beam momenta. The first is the change in longitudinal on axis field profile and the second is that due to changes in field profile the power coupling to the cavity changes and less power is accepted by the cavity.

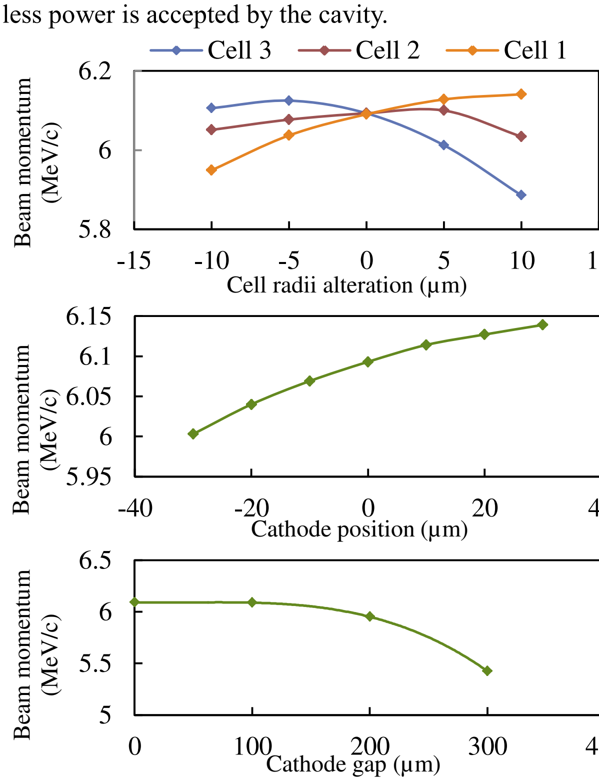

Figure 2: Effect of variations in cavity geometry on beam momentum at 8 MW cavity forward power.

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CATHODE METROLOGY

Four cathodes were investigated. Cathode 0 has been on recent operation on VELA. Cathodes 1, 2 and 3 were diamond turned to achieve a surface roughness of <6 nm RMS. The copper disk of these cathodes was 7.8 mm thick, 0.5 mm thicker than cathode 0 to ensure RF contact was at the cathode face and not the steel frame (see Fig.1).

A Fizeau interferometer and a Coordinate Measuring Machine (CMM) were used to measure the cathodes. Interferometry could not measure some areas of high curvature (as for the cathode 0 measurement) so CMM was required. As CMM marked the cathode surfaces cathode 3 was not measured while cathodes 1 and 2 had to be re-turned after the measurements. The metrology results are seen in Table 1.

Table 1: Dimensional Metrology of Cathode Faces

	Flatness from Interferogram (μm)	Flatness from CMM (μm)
Cathode 0	>14(some areas of cathode un-measured)	27±0.5
Cathode 1	-	64±0.5
Cathode 2	8.5	9±0.5
Cathode 3	16	-
Cathode 1 after re-turning	6	-
Cathode 2 after re-turning	10	-

The cathode faces were all higher in the centre than the edges, a typical example being shown in Fig. 3.

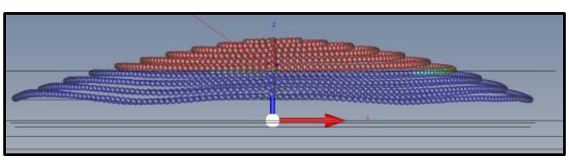

Figure 3: A typical cathode face enhanced deformation visualisation.

LOW POWER RF MEASUREMENT

Cathode Replacement Repeatability

As photocathode positioning has significant impact on the cavity tune the repeatability of replacing the cathode was investigated. The cathode recently used in operation, cathode 0, was removed and replaced, tightening the bolts in sequence in torque steps of 0.5 Nm. The π-mode frequency, coupling coefficient β, loaded and unloaded quality factors Q_L and Q_0 of the cavity were measured at each step. The original stainless steel bolts were replaced with molybdenum coated bolts that improved the frequency repeatability at a torque of 2 Nm from a standard error of 20.2 kHz to 11.57 kHz. Measurements were conducted at operating temperature and under dry N_2, and scaled to vacuum conditions.

The same procedure was performed on cathode 1, before it was re-turned. The standard error on frequency at 2 Nm for cathode 1 is 0.69 kHz, implying better, more repeatable RF contact.

The frequency measurements at the range of torques for both cathodes can be seen in Figure 4. The frequency of the cavity increases as the bolts are tightened and the RF contact improves; saturation then occurs in the RF contact and the frequency levels off. The same trend is apparent in the Q_0.

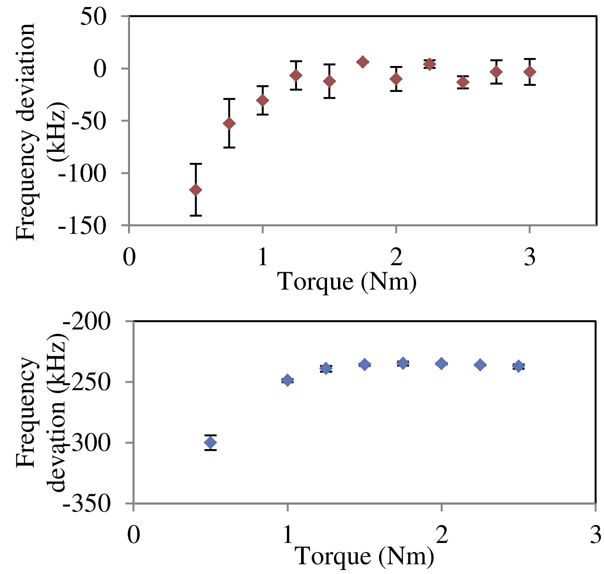

Figure 4: Cavity frequency deviation from 2.9985 GHz over a range of cathode bolting torques for cathode 0 (top) and cathode 1 (bottom).

Frequency Measurements

The resonant frequency of the cavity was measured with each cathode. This varies by up to 220 kHz using different cathodes. The results can be seen in Fig. 5.

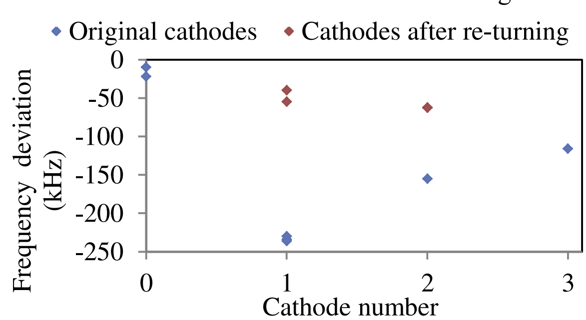

Figure 5: Frequency deviation from 2.9985 GHz measured with each cathode.

On Axis Field Measurements

The axial field distribution was measured using a bead-pull technique. A 0.5 mm diameter hole was drilled through cathode 1 for the string. The frequency of the cavity with cathode 1 did not change after drilling.

The field flatness is defined as the ratio of the absolute peak E field in the cell with the highest E field to the absolute peak E field in the cell with the lowest E field.

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With a cathode flatness of 64 µm the field flatness was very poor, 47%. After re-turning the cathode flatness improved to 6 µm and the field-flatness improved to 94%. The final field plot can be seen in Fig. 6. It is clear that field flatness is highly sensitive to the cathode shape.

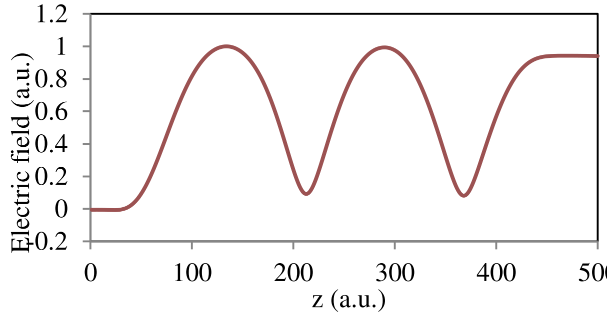

Figure 6: Axial fields in the cavity normalised to the field in the 3rd cell (left).

COMPARISON TO SIMULATION

A CST MWS simulation was performed modelling the cathode as a sine shaped dome over a range of peak deformations. The effect on frequency and field flatness of the deformation was recorded. This was compared to the measurements of the cathodes, with the expected plastic deformation from bolting the cathode into place (from Finite Element Analysis) added on. As the cathodes are not invariably dome shaped, notably cathode 0, and cathode 1 post re-machining; a perfect fit is not expected. Nevertheless most of the points do follow the trend. The plots can be seen in Figure 7.

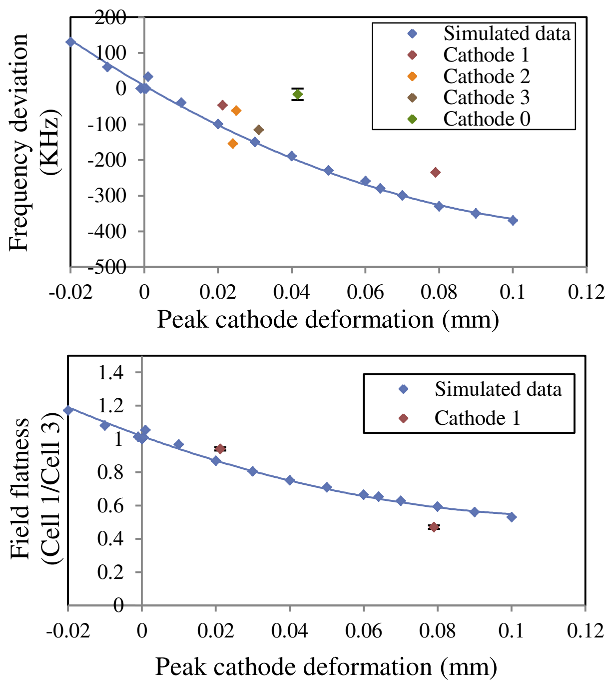

Figure 7: Comparison of simulated frequency (top) and field flatness (bottom) for deformed cathode to measured data.

Using these simulations and the measured data the field flatness of the cavity with cathodes 0 and 2 was estimated, and from this the final beam momentum was simulated. The results can be seen in Table 2.

Table 2: Comparison of Predicted Beam Momenta from Simulation and Measured Beam Momentum

	Beam momentum at 8 MW forward power
Average measured data from VELA	5.05 ± 0.19 MeV/c [4]
Predicted from CST model with ideal flatness and Q_0	6.08 MeV/c
Predicted from estimated field flatness and measured Q_0 for cathode 0	5.51 ± 0.4 MeV/c
Predicted from estimated field flatness and measured Q_0 for cathode 2	5.90 ± 0.1 MeV/c

CONCLUSIONS

The lower than expected beam momentum from the VELA photoinjector can be partly explained by the poor flatness of the cathode used and lower Q_0 achieved with this cathode. The cathode flatness was 27±0.5 µm. This accounts for up to 55% of the missing 1.03 MeV/c. Another contribution may be due to uncontrolled torque of the photocathode bolting for operation. A new cathode (cathode 2) will be used in the upcoming VELA operation. Simulation suggests an increase in beam momentum of 0.39 MeV/c with this cathode.

FURTHER WORK

The remaining loss of momentum could be explained by the close proximity of the 3π/5 mode to the operating mode. CST MWS simulations in the frequency domain show a phase shift of 3.65° per cell with respect to the neighbouring cell when excited on resonance. The resonant frequencies of the two modes are 3.4 MHz apart. Simulations will be performed to understand the effect of the phase shift on the beam.

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