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# SIMULATION STUDIES FOR DARK CURRENT SIGNATURE FROM DLS RF GUN

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*Abstract*

The Delhi Light source (DLS) is an upcoming compact THz facility at IUAC, New Delhi, based on pre-bunched FEL. RF conditioning of the 2.6 cell S-band RF gun is presently carried out with a Cu photo-cathode (PC) plug and dark current is produced when substantial accelerating field is reached inside the cavity. To identify the possible field emission sites contributing to dark current, single electron ASTRA simulations are done with a phase scan of the RF field. The simulation is extended to include multi-particle emission from the PC edge as a ring. The energies present in the dark current is analysed from the the Fowler Nordheim current plot and energy phase scan plot. The distribution of few dark current energies and their respective trajectories upto the YAG screen at a given solenoid setting is traced and shown in the simulations. We also present the dark current images captured during the initial RF conditioning and try to compare it with the simulations.

## INTRODUCTION

The Delhi Light source (DLS) at IUAC, New Delhi is a compact pre-bunched FEL facility designed to generate intense THz radiation in the range 0.18 - 3.0 THz [1, 2]. The facility is under commissioning stage and presently, the conditioning of the RF photo-cathode gun is underway. The photo-cathode gun is a 2.6 cell S-band RF cavity that is operated at 2860 MHz in pi mode. The cavity will generate a peak field of 120 MV/m when powered by a Klystron-modulator system at a peak power of ~ 15 MW. In order to study the persistent dark current expected to be produced during RF conditioning, theoretical simulations were carried out. The schematic of the beam line set up for dark current detection at a YAG screen (20 mm x 20 mm) placed at ~ 0.8 m from the photo-cathode placed inside the cavity is shown in Fig. 1.

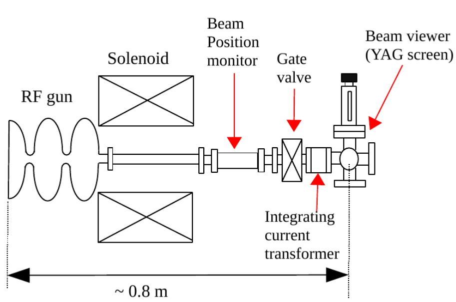


Figure 1: Schematic of beam line set up for dark current detection.

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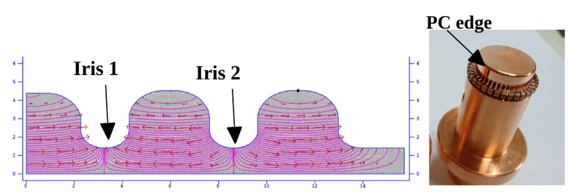
ASTRA [3] simulations performed by using typical cavity parameters shows that the distribution of energies present in the dark current can be tuned by tuning the solenoid field, which can be useful to know the dark current background for a given setting. Firstly, case studies with single electron simulations from the high field regions of the cavity was performed to identify the dark current source. Thereafter multi electron emission simulation was performed from the source identified by single electron simulations. The results are discussed in the following sections.

## SINGLE ELECTRON SIMULATIONS

The field emission current from high field regions of a cavity is given by Fowler-Nordheim equation as [4].

$$I_{FN} = \frac{1.54 \times 10^{-6} \times 10^{4.52/\sqrt{\phi}} A_e (\beta E \sin\theta)^2}{\phi} \times \exp\left(-\frac{6.53 \times 10^9 \phi^{1.5}}{\beta E \sin\theta}\right) \tag{1}$$

where, $\phi$ is the work function of emitting surface in eV, $\beta$ the field enhancement factor, $E$ the peak electric field in V/m, $A_e$ the effective area of field emission in cm$^2$ and $\theta$ the cavity RF phase.




(a) (b)

Figure 2: (a) Cavity field lines from SUPERFISH. (b) Cu Photocathode plug surface and its edge.

The regions around the irises and the circular edge (~ 8 mm) around the photo-cathode plug surface as shown in Fig. 2 are regions of strong field emission sites. Any scratch on the PC surface is also a contributor, but we assume the PC surface to be absolutely smooth. Not all such sites contribute to dark current as emission from most of the sites are lost within the cavity or do not reach the screen. Single electron simulation results at 30 MV/m peak field is shown in Fig. 3, which shows that the emission from the iris regions are mostly lost inside the cavity (Fig. 3(a,c)). The energy phase scan of iris2 (Fig. 3(d)) shows some energy gain over a small phase range, but such electrons end up in the beam line boundary as seen for the $0^o$ phase in Fig. 3(c). Finally it is seen from Fig. 3(e) that the trajectories from the photocathode (PC) edge can travel downstream without

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getting lost over a phase range from $0^o$ to ~ $60^o$ as reflected in the energy phase plot in Fig. 3(f). The PC edge can thus be considered as a potential source of dark current.

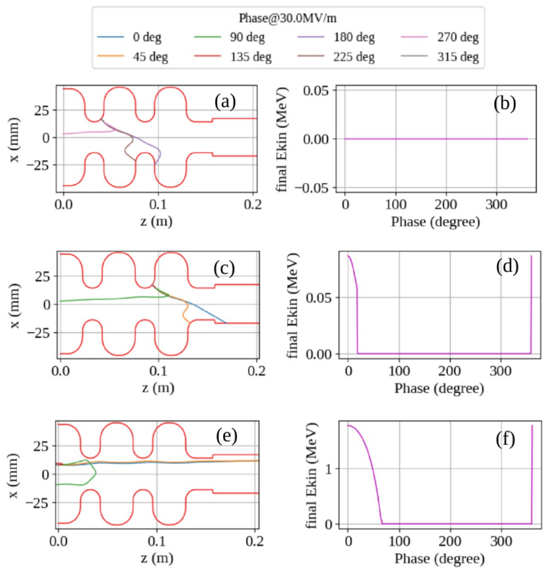


Figure 3: Single electron trajectory at different RF phase and corresponding energy phase plot at 30 MV/m peak field for emission from iris1 (a, b), iris2 (c, d) and PC edge (e, f).

## MULTI-PARTICLE SIMULATION

As discussed in the previous section the PC edge being a strong source of dark electrons [5], a dark current source in the form of a thin ring of radius ~ 8 mm along the edge of the photocathode plug was simulated. The simulations has been computed at 29 MV/m to compare the dark current observations as discussed in the next section. For the simulation, typical values of the input parameters were chosen, which is discussed below.

Considering an emitter with a field enhancement factor $\beta$ ~ 150 and a typical emitter area ~ $3 \times 10^{-10}$ cm$^2$, the Fowler Nordheim (FN) current at 29 MV/m is obtained as shown in Fig. 4. While the FN plot gives the charge distribution over the RF phase, the energy phase scan plot as obtained from ASTRA is also shown. The extent of phase overlap of the two plots decides the electron energies and their intensities in the dark current in a RF cycle. At higher cavity fields this overlap is more, implying presence of more energies in the dark current.

Computing the FN current in one RF cycle from a single emitter we have ~ 0.21 mA as the total current. With an emission tunnelling time computed ~ 1 fs [6], the total current translates to a total charge of ~ 0.21 atto-C. Finally, assuming all points on the ring of the PC edge with an assumed width ~ 0.1 µm about the radius, acts as ring type emitter, the total emitted charge of the ring in an RF cycle is computed to be ~ 35 fC. A temporal distribution of FWHM ~ 30 ps as obtained from the FN distribution plot, is used. The ring distribution at the photocathode, at the cavity

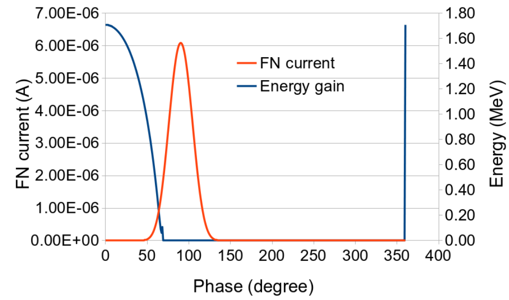


Figure 4: FN current plot and energy-phase scan at 29 MV/m.

exit and at the YAG screen for case with solenoid put-off is shown in Fig. 5.

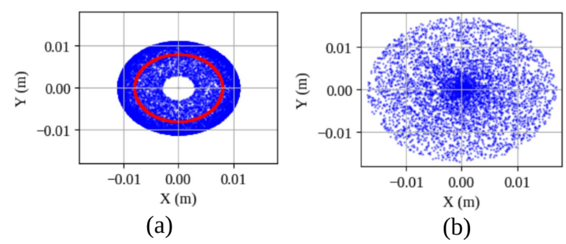


Figure 5: (a) Ring distribution at PC in red and the distribution at cavity exit (0.157 m) in blue. (b) the distribution at YAG screen.

Based on the simulations the electron distribution at the YAG screen will have a range of energies corresponding to the phase overlapped region of Fig. 3, with relative intensity given by the FN distribution. For the present case, a phase overlap from 55° to 68° with corresponding energy between 0.73 MeV to 0.0 MeV is seen from FN plot. The energy range obtained from simulation is between 0.7 MeV to 0.0027 MeV which is close to the calculated value. For a given solenoid setting (0.0352 T) the distribution of electrons of three different energies viz. 0.06 MeV, 0.12 MeV and 0.18 MeV in the screen is shown in red dots over other energies in blue dots along with their respective trajectories as shown in Fig. 6. This result shows that by simple tuning of the solenoid we can change the energy distribution of the particles in the screen. This can be useful to identify the dark current background at a given cavity field and solenoid setting.

## DETECTION OF INITIAL DARK CURRENT

The initial RF conditioning of the DLS RF gun has been done with a RF pulse of 4 µs with a repetition rate of 30 Hz and upto a maximum forward power of ~1 MW so far. The klystron power to peak field relation obtained from cavity bead pull data is given as $E_{peak} = 32.66\sqrt{P}$. where, $E_{peak}$ is in MV/m and $P$ is in MW. The persistent dark current image (ignoring the occasional random spots) at ~ 0.8 MW

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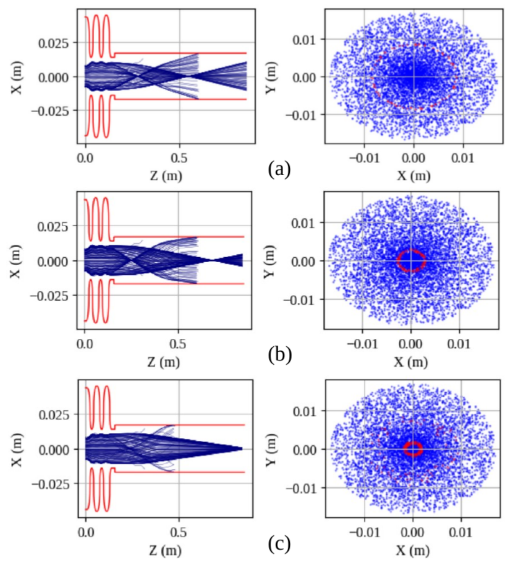
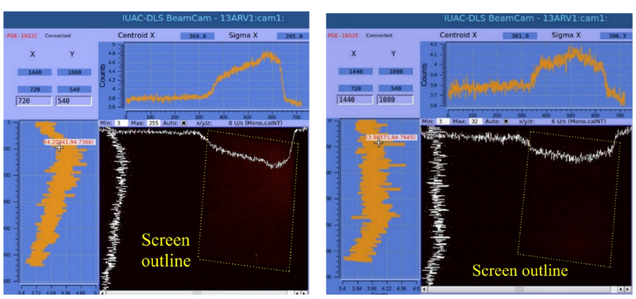
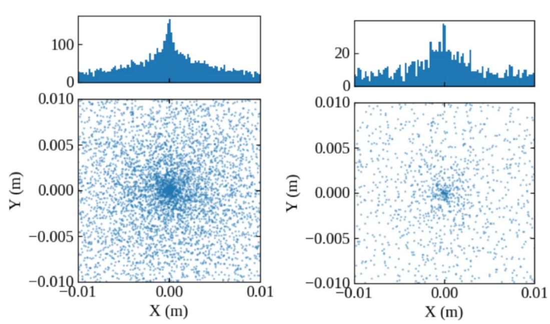


Figure 6: Particle trajectories (left plots) and their distribution (right plots) in red over other energies (in blue) at the screen for (a) 0.06 MeV (b) 0.12 MeV and (c) 0.18 MeV electrons at same solenoid setting.




(a) (b)

Figure 7: Captured dark current image at solenoid fields (a) 0.035T and (b) 0.095 T at the YAG screen.



(a) (b)

Figure 8: Simulated dark current image at solenoid fields (a) 0.035T and (b) 0.095 T at the screen position.

forward power, corresponding to a peak field of 29 MV/m and two solenoid field setting is shown in Fig. 7. The distribution from simulation at the corresponding solenoid setting is also shown for comparison in Fig. 8. Ignoring the distribution pattern, the decrease in the dark current intensity with higher solenoid current seems to agree with the observation. This is expected as the energies of the dark electrons are quite small (<0.7 MeV), making them over-focussed at higher solenoid fields. The difference in the pattern can be accounted to the fact that all the emitters may not necessarily be emitting to the same extent as assumed in the simulation and also there can be several other emitters on the PC.

## CONCLUSION

A simulation study on the emission of dark current from the DLS RF gun has been carried out. Single electron simulations to identify the prominent dark current source in the RF gun revealed that the edge of photo cathode plug can be a prominent source of dark electrons which can travel downstream. Using typical emitter parameters the Fowler-Nordheim current plot and the energy phase scan plot for an emitter (at PC edge) was plotted for a cavity field, and the energies present in the dark current was analysed. Extending the simulation for emission in the form of a ring from the PC edge, multi particle simulation was performed upto the screen. Trajectories of particles with certain energies was traced and their distribution with respect to other particles at the screen has been shown. The results indicates that by tuning the solenoid field the electron energy distribution at the screen can be changed. The study can be useful to identify the dark current background at a given cavity field and solenoid current.

The detection of actual dark current background for a couple of solenoid setting along with a comparison with simulation results has also been shown.

Further studies with dark current observation will be carried out when the RF conditioning will be performed at higher RF power from the Klystron.

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