DESIGN AND TESTING OF FARADAY'S CUP FOR NSLS-II LINAC AND BOOSTER*

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Abstract

NSLS-II will provide 500 mA, 3 GeV beam of 1 nm emittance. It's planned to have top-off operation. To ensure bunch uniformity and constant current, the precise measurement of the charge becomes necessary. There are three Faraday Cup's at the end of the transport line in the Linac and Booster transport lines which serve this purpose. The details of the design consideration are presented in this paper. The Diagnostic group at NSLS-II, designed, prototyped and tested the Faraday Cup (FC). Power density calculations and FEA simulations were carried out for the three cases.

INTRODUCTION

At NSLS-II, the FC's serve as a beam dump and a charge measuring device, therefore we have three such devices at the end of each of the test beamlines. The beam energy in the Linac area is 200 MeV [1]. The beam size at FC1 and FC2 in the Linac transport line was found to be 0.2 mm horizontally and 0.5 mm vertically. Figure1 below indicates the location of FC1 and FC2 in the Linac area. Figure 2 indicates FC3 in the Booster area. The beam energy in the Booster area is 3 GeV with a beam size of 2.3 mm in the horizontal direction and 0.27 mm in the vertical direction.

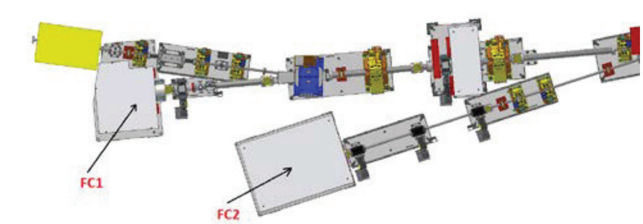

Figure 1: Location of Faraday's Cup in the linac area.

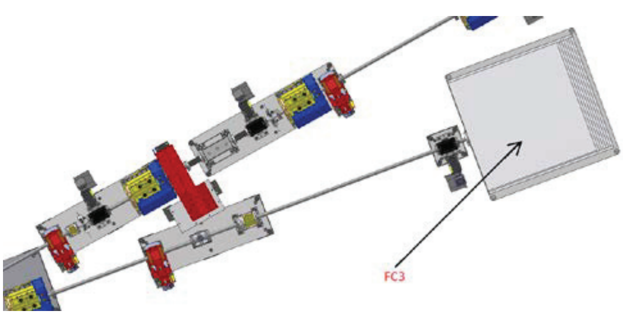

Figure 2: Location of the Faraday's Cup in booster area.

- Different devices are used to measure beam current. One way to measure the total charge of the beam in normal operation is by non intercepting devices such as current transformers (ICT, and DCCT). This non destructive method is independent of beam energy. These devices have to be calibrated to a device that will collect the totality of the electrons. For this reason an FC have to be installed close to the device to be calibrated (unknown losses between the two instruments introduce systematic errors).
- Another method to measure the charge is by using FCs. In this case, we need to stop and dump the electron beam for a certain period, preferably at full energy and bunch repetition rate. FCs are installed at the end of the transport lines. The beam will be sent to the FC during beam tune ups. Beam stops are used to absorb the entire beam.

MECHANICAL DESIGN

The designed Faraday Cup consists of a beam stop (graphite and copper pieces), which is essentially used to stop the beam. This is followed by a beam dump (stainless steel pieces). Details of this design are indicated in Figure 3.The radiation shower produced after stopping the beam must be absorbed. This is achieved by using layers of lead and borated polyethylene sheets. The third most critical component of the Faradays cup is its electrical circuit, which consists of an integrator followed by a digitizer. The ceramic brake isolates the beam dump from the rest of the assembly. The charge is measured by integrating the output voltage across the ceramic break. The beam dump consists of six plates which are one inch thick made of SS-304 and are bolted together. A knife-edge seal would ensure that the integrity of vacuum is maintained. This is machined on the first plate face of the SS-304 plate.

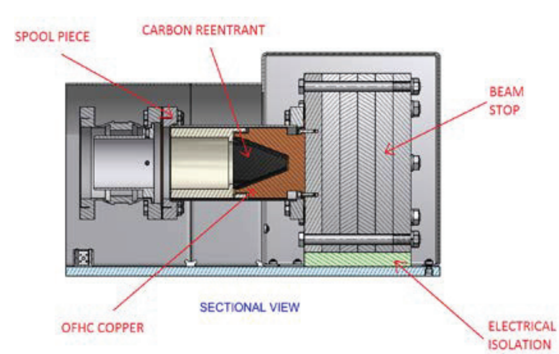

Figure 3: Construction details of FC.

A carbon graphite cone is used mainly to reduce backscatter after beam stop shower. A spool piece is used to attach the components downstream of the beam stop. To prevent ozone generation, the front of the cup is in vacuum. Lead bricks are used for blocking the radiation and these bricks are surrounded by High Density Polyethylene (HDPE) sheets for shielding neutron radiation. The thickness of the lead and poly shields is based on the Linac and Booster beam parameters and was determined using Monte Carlo simulation. Typical lead and HDPE shielding configuration is shown in Figure 4. Shielding was provided in layers of lead and poly thickness to each of these dumps to block the radiation remaining from the steel plates, which is around 67.6KeV for FC3. The carbon re-entrant cone was machined at a cone angle of 30 degrees [2].

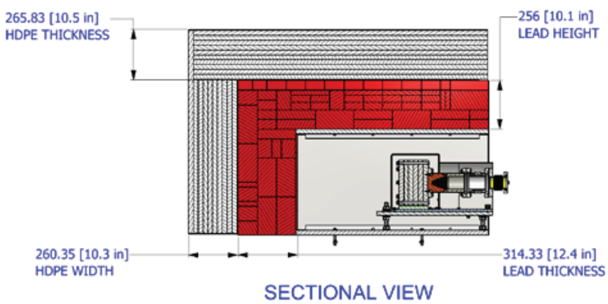

Figure 4: Shielding thickness for FC.

TESTING AND CALCULATION RESULTS

While penetrating the layers of the Faraday's Cup, the electrons interact with the material atoms both elastically and inelastically. For electrons with energy higher than tens of Mev, the energy loss is mostly through Bremsstrahlung, and can be well described by

$$E(x) = E_0 e^{-x/x_0} . \tag{1}$$

Where E0 is the initial energy and the radiation length

$$X_0 = \frac{716.4A}{Z(Z+1)\ln(287\sqrt{z})} g \cdot cm^{-2} . \tag{2}$$

With A as the atomic number and z the charge number.

The beam divergence, however, is mostly affected by the frequent Coulomb scattering with the nucleus. The angle growth rate is given by

$$\Delta\theta = \frac{13.6MeV}{\beta cp} z\sqrt{x/x_0}[1+0.038\ln(x/x_0)] . \tag{3}$$

To calculate the heat deposition and radiation issues, we consider FC3, which is subjected to most severe conditions. The initial beam size is calculated from the lattice functions, i.e., the emittance from the Booster is 40/4 nm in x/y; the relevant lattice functions at the entrance of the dump are $\beta_{x/y}$ =128.2/176.0, and $\gamma_{x/y}$=1.7/1.0. The subsequent angle and beam size were obtained by integrating Eq.(3). The beam property for FC3 is summarized in the following table.

Table 1: Beam Parameters through Materials for FC3

Material	L mm	X_0	ΣX_0	E_0 eV	σ_x mm	σ_y mm
start	0	0	0	3G	2.3	0.27
Graphite	76.8	0.45	0.45	1.9G	10	2.8
Copper	23.8	1.65	2.1	0.36G	44	23.4
Steel	151.2	8.6	10.7	67.6K	*	*

*The beam turns into a shower at the end of the steel plates. Beam size was also calculated based on the thicknesses and materials of each of these components. For the Linac FC, the beam size on the graphite surface was found to be an ellipse of 20 mm width and 24 mm height. The beam power is deposited on the surface as a conservative approximation. As can see in fig. 3, for a charge of 15 nC in the linac area, the maximum temperature was found on the graphite is 35 Degree C.

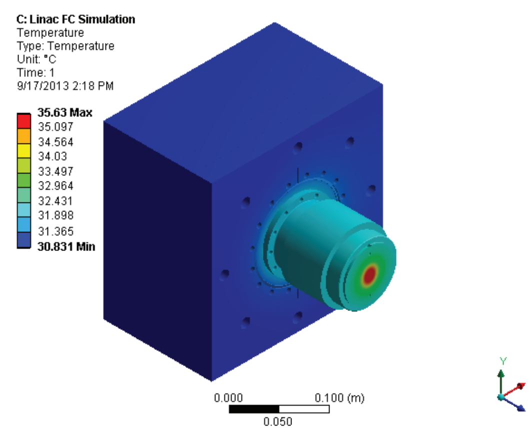

Figure 5: FEA simulation of linac transport line FC.

For the Booster FC, considering the charge of 10 nC, the total power was around 30 W, with maximum Temperature of around 196 Degree C.

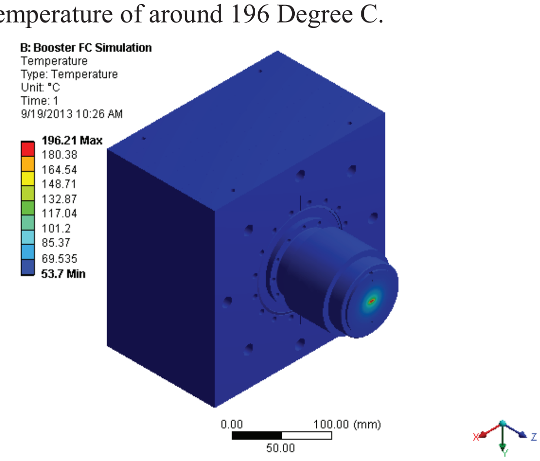

Figure 6: FEA simulation of booster transport line FC.

DESIGN OPTIMIZATION

Ensuring the accuracy of charge measurements require careful attention and accounting for all the error sources. In reality there are multiple reasons for electrons losses that must be considered during the design phases.

ISBN 978-3-95450-138-0

- Penetration losses: Adequate size (radius and length) of the beam stop with a safety margin was calculated for preventing penetration losses. The design ensures that the width of the dump is 5 times the radiation length on both sides.
- Backscatter losses: The conical shape of the beam stopper reduced the electrons escape solid angle [3]. Graphite used has a low atomic number than the high Z value which helps the beam stop to slow the incoming beam and allow all the particles to flow to the conductive dump.
- Current leakage: Charge leakage due to insufficient impedance to ground may occur in the FC system: FC itself (support structure and enclosure), RF cables, integrator, or digitizer. The insulation is made of very high resistance material (G10 plate 0.75 inch thick). A known source was connected in parallel to the Faraday cup during integration tests, and leakage charge was found to be negligible (< 1pC).

BEAM MEASUREMENT

An RC network integrates the cup output voltage for measurement by a digitizer DC252 (4GS/channel, 2 GHz bandwidth, 10 bit resolution). The FC will be used to cross check the ICT's reading. To reduce signal loss, a low loss RF cable LMR900 is used to connect the FC to the digitizer. Figure 7 illustrates the bloc diagram of the FC system. The charge is calculated by integrating the voltage pulse area over a designated region of interest (ROI). $Q = \frac{1}{R}\int v.dt,$ where R = digitizer input impedance. The digitizer output waveform is displayed in the control room from the appropriate CSS panel. Figure 8 is a screen shot of beam measured by the transport line FC2.

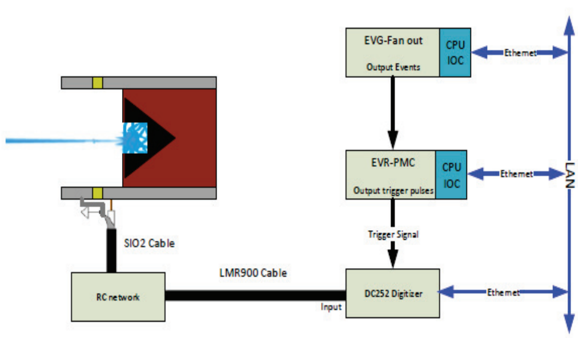

Figure 7: Block diagram of the FC measuring system.

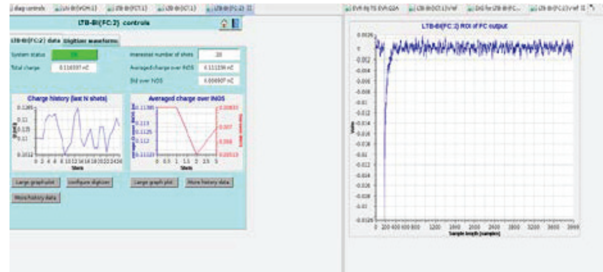

Figure 8: Transport line FC measured beam.

Figure 9: BINP FC VSWR measure- 20 GHz span.

CONCLUSION

During LINAC commissioning we have seen that FC1 does capture close to 100% of the beam seen at ICT1, while FC2 captures about 85% of the beam (FC1 closer from ICT1 than FC2). To measure the time structure of the beam FC1 will be replaced in the future by a wide bandwidth coaxial Faraday cup [3].

The heat simulation studies outlined above also indicate that the booster dump is much hotter than Linac dump but well within the melting point of graphite, hence a safe design.

REFERENCES

[1] R.P Filler et al., "NSLS-II Transport Line Progress", IPAC, 2012.

[2] Morgan, AFD et al., "Design of Faraday Cup at Diamond", DIPAC 2005, p.51.

[3] Jing Hu et al., "Faraday cup with nanosecond response and adjustable impedance for fast electron beam characterization", American Institute of Physics, July 2011.