DESIGN OF THE FARADAY CUPS IN DIAMOND.

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Abstract

This paper details the work done on the design of the faraday cups for the DIAMOND light source. Diamond has faraday cups in positions covering the complete energy range of the machine from the 90keV gun to the 3GeV storage ring.

The Linac cups were modified from an existing design, while the higher energy designs were done using Monte Carlo code. The Monte carlo led designs achieved an electron capture rate of around 99%, allowing them to be used with reasonable certainty as calibration references.

Due to the modest 5Hz repetition rate of the electron gun, power loading of the structures is minimal and active cooling is not required for any of the cups.

Ablation is also not thought to be a significant problem for these designs.

OVERVIEW

Diamond light source is a 3GeV 3^{rd} generation synchrotron. The electrons are initially ejected from a 90keV gun. A linear accelerator increases the energy of the electrons to 100MeV. A booster ring further increases the energy to 3GeV. Finally the beam is injected into the storage ring to generate the synchrotron radiation [1].

Faraday cups are a basic charge capture device which can be used as reference points for current measurement calibration. Diamond has faraday cups after the 90keV gun and the 4MeV bunching section, in the linac to booster transfer line at 100MeV and at 3GeV in the booster to storage ring transfer line.

An initial design decision was made to make the designs passive to increase reliability and reduce complexity.

Due to the modest 5Hz repetition rate of the electron gun, power loading of the structures is minimal and active cooling is not required for any of the cups.

The 90keV and 4MeV cups were modified from an existing design using analytical formulæ and MathCAD. Monte carlo modeling was used to confirm the new design. The high energy 100MeV and 3GeV designs were done using the EGSnrc Monte Carlo code[1] from the national research council Canada, with MatLAB being used for interfaces and post analysis.

This paper will cover the basic methodologies used to obtain each design as well as the final design details and expected performance.

[1]http://www.irs.inms.nrc.ca/inms/irs/EGSnrc/EGSnrc.html

THE LINAC FARADAY CUPS

The 90keV/4MeV cup is an in vacuum design, based on the SLS 90keV design [2]. The design maintains the coaxial structure as much as possible in order to obtain a high bandwidth (figure 1).

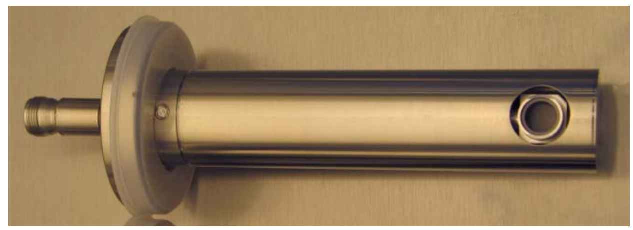

Figure 1: The linac faraday cup assembly

The design changes were calculated using analytical formulæ taking into account collisional losses, radiative losses due to bremsstrahlung, the photoelectric effect, compton scattering and pair production. The final design was verified using the EGSnrc code (figure 2).

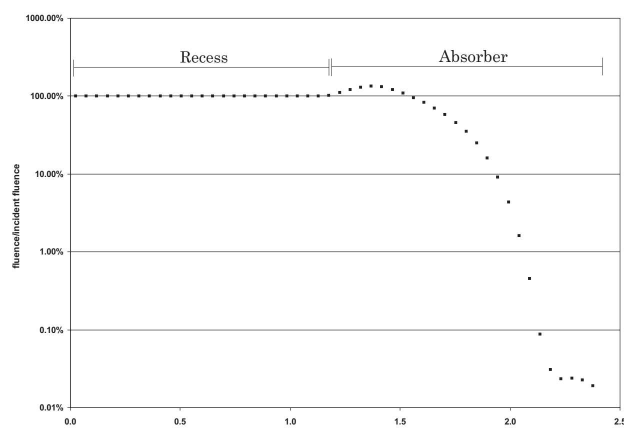

Figure 2: Data from the EGSnrc code

The cup is mounted on an actuator to enable it to be inserted into the beam path of the linac. The main absorber is made from a 24mm aluminium block with a 12mm deep recess cut into it. This enables the design to work at both 90keV and 4MeV.

At this energy the backscatter from the absorber block is the dominant effect. The recess diameter was chosen to be 13mm to accomodate some beam movement while still keeping backscatter low. A carbon cup with 1mm wall thickness was inserted into the recess to act as a soft stop to reduce the backscatter from 12% to 3.5% in the 90keV case, and from 2.5% to 0.7% at 4MeV (figure 3). Thus we expect the cups to perform with greater than 90% electron capture efficiency.

Figure 3: Close up of the absorber

The cup was tested in the 90keV position during the linac gun tests by PPT. Figure 4 shows the signal from the cup in response to the single bunch output of the gun.

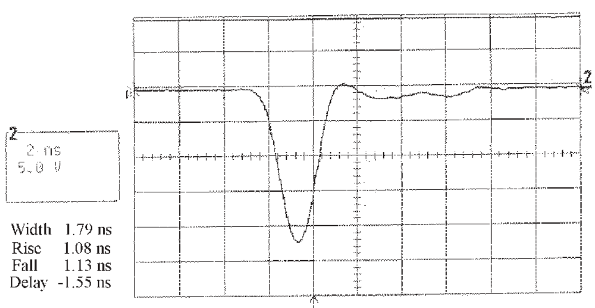

Figure 4: Data from initial test

This shows that the cup behaves as expected.

THE 100MEV DESIGN

The 100MeV faraday cup is an in-vacuum design directly connected to the machine vacuum. A solid block of oxygen free copper was used for the main absorber due to its superior heat conductivity, allowing it to thermalise the heat spikes caused by the electron bunches quickly enough to reduce power loading to negligible levels.

The absorber block is suspended off ceramic washers to give it electrical isolation while a recess and carbon soft stop were used to reduce backscatter (figure 5).

The absorber section is a cylinder with a diameter of 160mm and a length of 250mm, with an additional 100mm for the recess. The total mass of copper used is 84.5kg.

The recess diameter of 63mm was chosen to match the beam pipe diameter in order to ensure beam capture (both

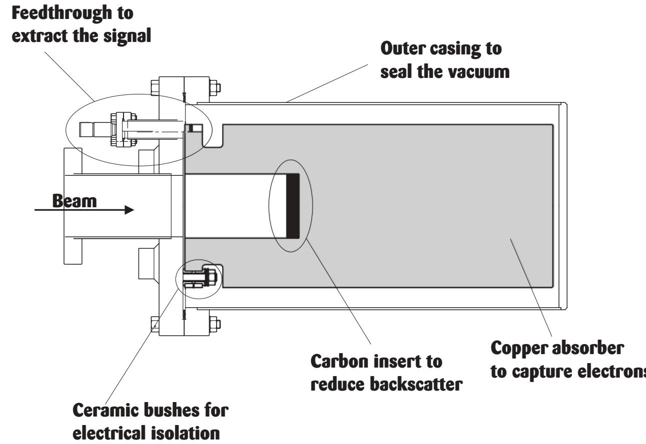

Figure 5: The design of the 100MeV device

high energy designs also act as beam stops). Making the recess opening larger does not have much effect on the capture efficiency as backscatter reduces as the energy increases.

Ablation of the cup was considered but the energy density at the cup is below the surface ablation limit of Copper (10^7W/cm^2) [3]. From the EGS results, this design is expected to have an electron capture efficiency of 99.2%.

THE 3GEV DESIGN

The 3GeV design is also a copper absorber with carbon soft stop. The absorber will be constructed out of several plates. The front plate is made from oxygen free copper and will be braised to the 38mm diameter vacuum tube.

A ceramic break in the vacuum tube gives the electrical isolation needed for the cup to work, while a bellow gives mechanical isolation between the absorber block and the break.

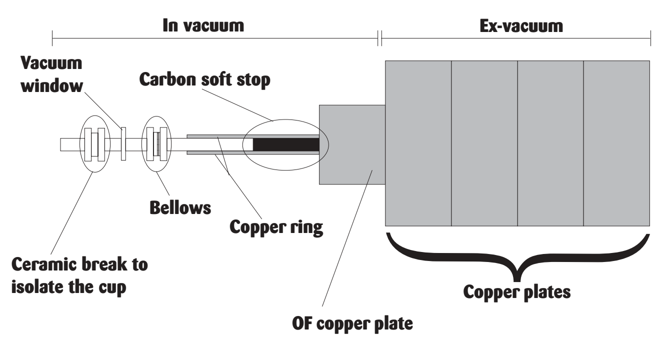

Figure 6: The design of the 3GeV device

The front of the cup is in a vacuum environment to eliminate the problem of ozone generation if the beam were to pass through air. However, it is separated from the main machine vacuum using a vacuum window in order to eliminate the risk from outgassing and from possible ablation.

The rest of the absorber will be constructed ex-vacuum using a stack of additional copper plates. The soft stop to reduce backscatter in this case is a carbon cylinder inside the vacuum tube, while a ring of copper surrounds the tube to capture the remaining backscatter (figure 6).

From the monte carlo results the design has an electron capture level of 99%.

The total length of the absorber is 500mm. The front plate is 100mm thick in the beam direction and has a 240mm diameter. The ex vacuum plates are 100mm thick in beam direction with a minimum diameter of 500mm.

The thickness of the copper ring was studied and an optimum thickness of 51mm was reached by balancing the secondary electron capture against the number of electrons escaping from the resulting cascade.

The total mass for this design is 957kg.

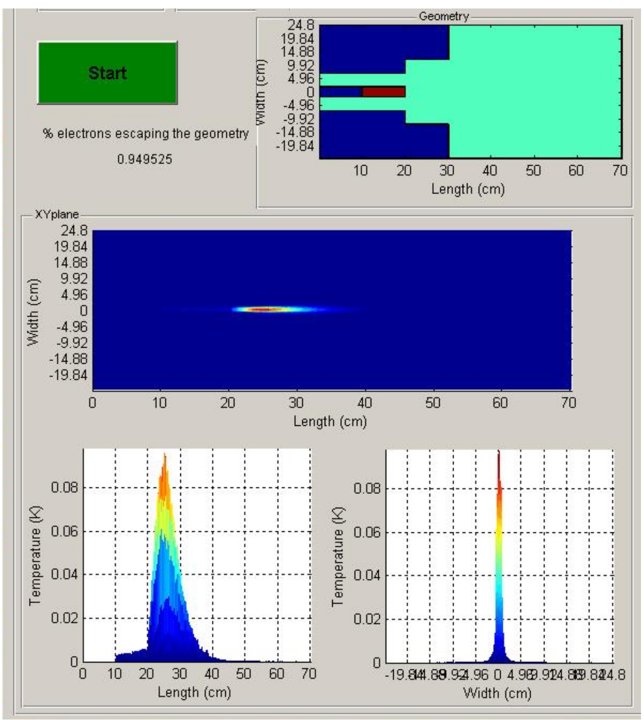

Figure 7: Thermal data for the 3GeV design for a single shot

For this position in the machine the energy density could go above the surface ablation limit of copper if a large portion of the energy was deposited near the surface. However, the majority of the energy was found to be deposited some centimeters into the structure with little deposited near the surface (figure 7). Thus surface ablation effects are not thought to pose a large risk.

CONCLUSIONS

Designs have been developed for all of the faraday cups in the DIAMOND machine. The 90keV and 4MeV designs are expected to exceed 90% electron capture while the results from the EGSnrc code show capture efficiencies of 99.2% for the 100MeV cup and 99% for the 3GeV cup.

Due to their passive designs these capture efficiencies should have a low error on them, allowing all the designs to be used with confidence as calibration sources for current measurements.

Power loading and surface ablation are not thought to be significant problems for these designs.

The linac faraday cup has been tested in the 90keV position and has performed as expected.

References

[1] R. P. Walker Progress with the diamond light source, Proceedings of EPAC 2004.

[2] V. Schlott SLS LINAC AND TRANSFER LINE DIAGNOSTICS, PSI Scientific Report 1999, Volume VII Swiss Light Source.

[3] A. Bogaerts Z. Chen R. Gijbels A. Vertes Laser ablation for analytical sampling: What can we learn from modeling?, Spectrochimica Acta Part B 2003 pp 1867-1893.