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REALIZATION OF A FARADAY CUP FOR THE GUN OF PERLE

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Abstract

Faraday Cups (FC) have been used as diagnostic tools to measure the charged particle beam current directly. Up to now, different designs have been introduced for this purpose. In this work, a new design of Faraday cup has been performed for the gun of PERLE, a Powerful Energy Recovery Linac to be installed at IJCLab Orsay. FC's dimensions and desirable material have been considered based on PERLE Gun beam characteristics (maximum energy of 350 KeV and maximum current of 20 mA). Appropriate specifications were written for this FC. In addition, the heat power generated by electron collision with FC material has been calculated and the required cooling system has been specified. The Faraday cup is realized and tests should be run early next year to measure the electron beam current out of PERLE gun.

INTRODUCTION

The PERLE facility represents a new generation of energy recovery machines. It operates in the 10 MW power regime, handling a beam current of 20 mA. The nominal beam energy reaches 500 MeV, marking a significant milestone in ERL development.

PERLE is designed as a compact, multi-pass energy recovery linac. Its architecture relies on superconducting radio-frequency (SRF) technology. The primary goal is to serve as a testbed for accelerator physics studies. It also provides a platform for validating technical choices for future projects.

A schematic overview of the machine is presented in Fig. 1. On the far right is the photocathode gun, which generates the electron beam. This is directly followed by the injector section, feeding the main accelerator.

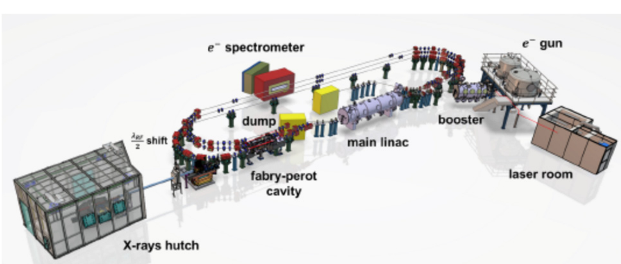

Figure 1: An overview of PERLE.

In the initial setup, the maximum beam energy is limited to 250 MeV. This energy is achieved through three successive passes in a single SRF cryomodule. The injector delivers the beam with a starting energy of 7 MeV.

The first phase, scheduled for late 2028, focuses on commissioning the injector. This includes testing the high current electron gun.

Standard diagnostics are installed, two BPMs with integrated steerers will monitor the orbit of the beam. The beam transverse profile is monitored thanks to a view screen. Finally, a Faraday cup (FC) will measure the beam current profile.

The scope of this document is to detail the specifications, the design and the realization of the Faraday cup mentioned above.

With each pass, the beam gains approximately 82.2 MeV. The intermediate energies obtained are 89 MeV, then 171 MeV. Finally, after the third recirculation, the beam reaches 250 MeV. At this point, the beam path is shifted by half an RF period. This precise phase adjustment enables the deceleration process to begin. The beam then re-enters the same linac structure in a decelerating mode.

During this stage, the previously gained energy is gradually returned to the RF system. As a result, the beam is slowed back down to 7 MeV, its injection energy. It is then directed to the beam dump, where it is safely absorbed. This operation demonstrates the principle of multi-pass energy recovery. It also validates operation at high beam current with efficient energy reuse.

Looking towards the future, a second project phase is already under consideration. This upgrade would add a second SRF cryomodule in the opposite straight section. Such an extension was anticipated in the conceptual design report [1]. The additional module would significantly enhance machine performance. In doing so, PERLE will remain a key facility for advancing accelerator research.

FARADAY CUP SPECIFICATIONS

During the start-up and commissioning phases of PERLE gun and injector, the beam current is measured either with non-interceptive or interceptive devices. The Faraday cup is included in the latter category. It serves as beam destination and measures the beam current. Faraday cup should withstand the nominal beam pulses with a charge up to 500 pC and a repetition rate up to 40 MHz, which corresponds to a beam mean current up to 20 mA. The gun would deliver an electron beam with an energy set to 350 keV.

The Faraday cup would operate under two configurations:

- Configuration 1: a beam current up to 20 mA with a repetition rate of 40 MHz and a beam transverse size down to 3 mm RMS.
- Configuration 2: a beam current up to 5 mA with a repetition rate of 10 MHz and a beam transverse size down to 1 mm RMS.

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The Faraday cup must at least withstand a beam power of 7 kW. The Faraday cup pipe diameter is set to 50 mm. The cup is entirely made of copper and water cooled. The cup is inserted or extracted from the beam line by means of a pneumatic actuator. In order to block the secondary emissions, an electron suppressor is integrated to the Faraday cup. A Bias of 2 kV should be enough for a proper operation of the suppressor. The Faraday cup measures the average beam current. The repetition rate of this measurement ranges from 10 Hz to some tens of kHz. Mechanical, electrical, vacuum and cooling specifications of the FC are detailed in Table 1.

Table 1: Faraday cup additional specifications

Parameter	Precisions
Actuator material	304L or 316L
Air pressure	6 bar
FC depth along beam axis	<300 mm
FC supporting flange	Up to DN 200
Electrical insulation	>500 MOhms
Water pressure	10 bar at 20 °C
Inlet water temp	20 °C
Cooling liquid	De-ionized water
Water circuit leak rate	$<1\times10^{-9}$ mbar L/s
Vacuum leak rate	$<1\times10^{-9}$ mbar L/s

The Faraday cup for PERLE gun was designed and produced at NTG [2]. The actual cup is entirely made of copper and water cooled.

FARADAY CUP DESIGN

The FC head profile is sketched in Fig. 2: an aperture disk on the far left is set to detect the presence of the beam.

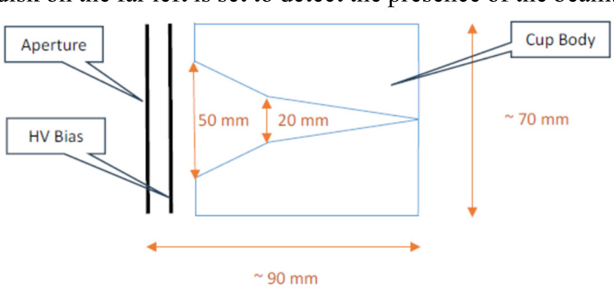

Figure 2: Faraday cup head profile.

A HV bias disk is set to suppress secondary emission electrons. Two plates are arranged with slope aspect regarding beam incidence angle. With this configuration, a maximum of 7.5 kW is supported in configuration 1 and a maximum of 3 kW is supported in configuration 2. The simulated heat maps of the FC for both configurations are sketched in Figs. 3 and 4.

The temperature does not exceed 500 °C, far away from the copper melting temperature (1000 °C). The cooling system only requires a water flow of 5 L/min for a temperature increase less than 20 °C. Also the FC supporting flange is a DN160CF.

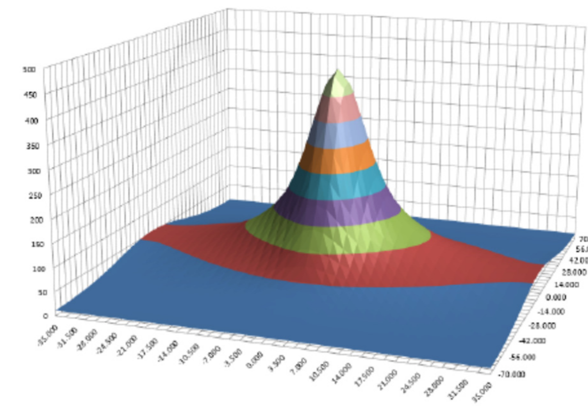

Figure 3: Faraday cup heat map for beam configuration 1.

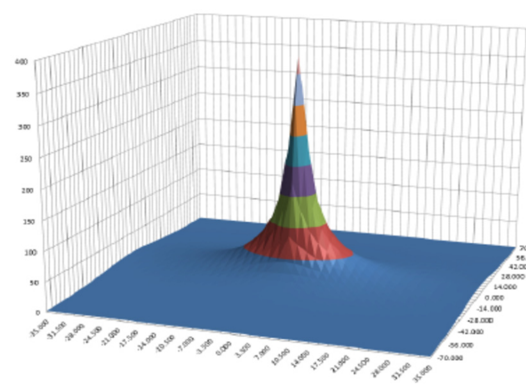

Figure 4: Faraday cup heat map for beam configuration 2.

FARADAY CUP INTEGRATION

The FC was delivered early September 2025. Meanwhile, a metallic cross was realized for FC integration and vacuum pumping. The FC will be mounted vertically as mentioned in Fig. 5. The FC head is by default inside the beam pipe.

The Faraday cup uses an ultra-high vacuum system to minimize particle interference. Ion pumps are typically employed. These pumps progressively reduce pressure to reach a vacuum leak rate about 10^{-11} mbar L/s.

The system must be carefully baked (120 – 250 °C) to remove adsorbed gases from surfaces. All seals are metallic, and materials are chosen for low outgassing.

The system uses UHV-compatible materials to maintain integrity. Pressure is monitored using different vacuum gauges at each stage. These gauges ensure accurate pressure control to maintain UHV during Faraday cup operation. This ultra-high vacuum minimizes background noise and improves measurement accuracy.

NEXT STEPS

The FC interface for operators is under development. It will allow to control cooling, motion of the actuator and

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current measurements. This interface will serve as starting point for the operation and control of other FCs, and it will help in the implementation of interlocks and alarms on relevant process variables.

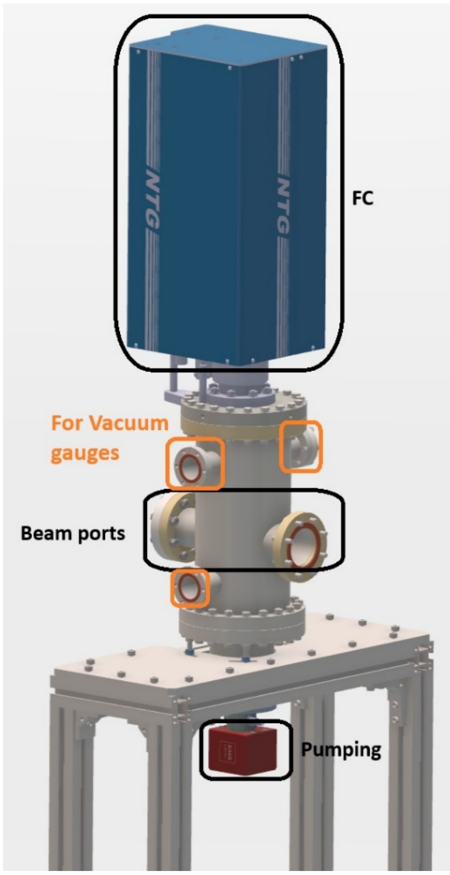

Figure 5: Faraday cup integration.

CONCLUSION

The steps for the realization of PERLE gun Faraday cup are reported. The FC is at the most advanced stage. The expected commissioning of the PERLE gun will help us in the design and the realization of a future FC for the injector. The experience accumulated during the commissioning of PERLE gun will be useful for other FC systems.

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