PERFORMANCE TESTS OF A SHORT FARADAY CUP DESIGNED FOR HIE-ISOLDE

E. D. Cantero, W. Andreazza, E. Bravin, M. A. Fraser, D. Lanaia, A. Sosa, D. Voulot,
CERN, Geneva, Switzerland

Abstract

The On-Line Isotope Mass Separator (ISOLDE) facility at CERN is being upgraded in order to deliver higher energy and intensity radioactive beams. The final setup will consist in replacing the energy variable part of the normal conducting REX post-accelerator with superconducting cavities. In order to preserve the beam emittance, the drift space between the cryomodules housing these cavities has been kept to a minimum. As a consequence, the longitudinal space available for beam diagnostics is severely limited in the inter-cryomodule regions. A Faraday cup (FC) will be installed to measure beam currents, and due to the tight spatial constraints, its length is much smaller than usual. This poses a great challenge when trying to avoid the escape of ion-induced secondary electrons, which would falsify the current measurement. Two prototypes of such a short FC have therefore been tested at REX-ISOLDE using several beam intensities and energies, with the aim of determining its accuracy. In this paper the experimental results obtained for the two prototype cups are presented together with numerical calculations of the electrostatic fields that are produced inside the cup.

INTRODUCTION

The High Intensity and Energy ISOLDE project (HIE-ISOLDE) consists of an upgrade of the current facility in order to increase the intensity and energy of its delivered radioactive ion beams [1]. The energy upgrade of the post-accelerator is based on superconducting quarter-wave cavities housed in common cryogenic modules. The reduced longitudinal dimension for the beam diagnostics system placed between the cryogenic modules is a limiting factor for all the instruments, and in particular for the Faraday cups that will be used for beam current measurements [2].

A typical design of a Faraday cup is shown in Figure 1. The beam of charged particles is stopped on an isolated metal cup connected to a picoammeter, which is used to measure the beam total electrical current. The interaction of the beam with the collector produces the emission of secondary electrons. If these electrons are not redirected back and stopped in the collector the reading of the beam current is affected by the loss of negative charges. The electron loss from the collector is observed on the picoammeter exactly as if a positive charge has been collected, this process therefore affects the reading of the beam current and needs to be supressed. Most of the ion-induced secondary electrons are emitted with energies below 20 eV, but also high-energy backscattered electrons are emitted, with energies up to some keV [3]. To prevent the loss of the low-energy secondary electrons, a repeller is installed in front of the collector, connected to a negative potential (typically -60 V) with respect to ground level. Secondary electrons are also collected at the cup walls, which implies that the collection factor increases for larger ratios between the cup length and its diameter.

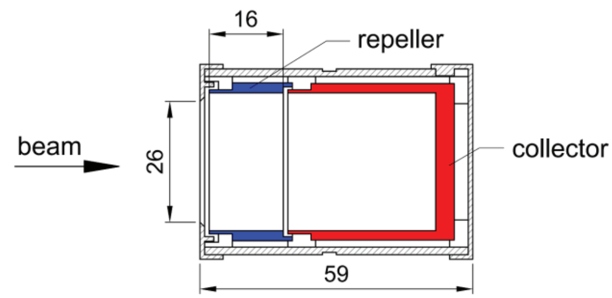

Figure 1: Layout of a standard Faraday cup , used at ISOLDE. Dimensions in mm.

We have designed two prototype Faraday cups that have a considerably large aperture (diameter 30 mm) with respect to its very short longitudinal dimension (overall length 14 mm). These prototypes have been tested at ISOLDE using stable ion beams ($^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$) in the energy range between 0.30 and 2.85 MeV/u.

DESIGN CONSIDERATIONS

Two different prototypes were produced for the short Faraday cup, a cross-section of their geometry is presented in Figure 2. The insulating pieces of the prototypes were manufactured in Vespel and the metallic pieces in aluminium. Prototype 1 has a short repeller length (1.5 mm) and includes a grounded guard ring between the repeller and the collector, in order to reduce the influence of leakage currents. Prototype 2 was designed with a larger repeller length (7.5 mm) and without the guard ring.

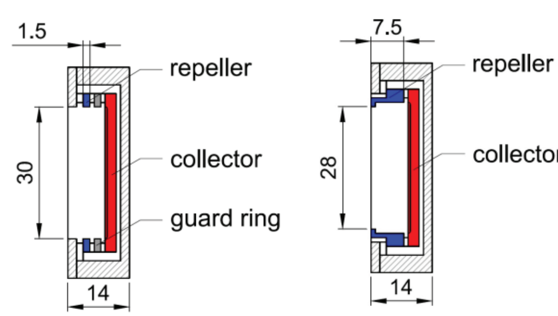

Figure 2: Layout of the prototype Faraday cups. Dimensions in mm. Left: Prototype 1. Right: Prototype 2.

Due to the very short longitudinal space available, the design of the Faraday cup for HIE-ISOLDE is atypical, because its collector is a plane electrode instead of cylindrical cup. As a consequence, the loss of electrons is only supressed by the applied negative potential. In the case of prototype 1, the very short repeller length is a limitation for the height of the potential barrier at the cup axis, which is severely reduced in comparison with a standard Faraday cup, where the repeller length is of the order of its radius.

EXPERIMENTAL SETUP

The prototype Faraday cups were installed in a diagnostic box at the REX-ISOLDE postaccelerator, see Figure 3.

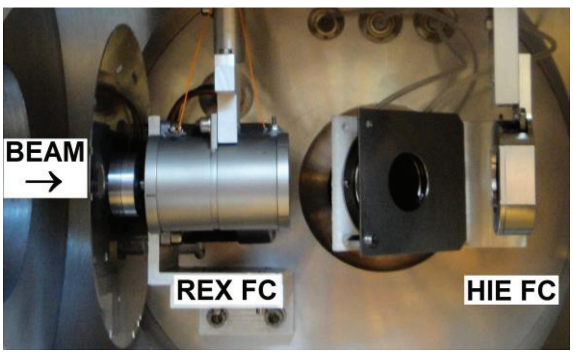

Figure 3: Experimental setup. The short prototype (HIE) FC was installed in a diagnostic box, which also includes a collimator wheel and a standard (REX) FC.

A standard Faraday cup from REX-ISOLDE was used as a reference for the total beam current values. Possible effects coming from different beam shapes were studied by placing circular or linear collimating slits upstream the cups. As expected, no beam shape influence was observed in our measurements.

ELECTROSTATIC FIELD CALCULATIONS

In Figure 4 we present contour maps for the electrostatic potential inside the two prototype cups. Due to its very short repeller length, the height of the repelling barrier for electrons in prototype 1 is severely reduced at the cup axis, and therefore to supress the emission of low energy electrons a biasing of the repeller of -500 V needs to be applied. The radial dependence of the electrostatic potential is considerably high. On the other hand, an equivalent potential barrier height can be obtained in prototype 2 for a supressing potential of -100 V, due to its longer repeller length. The radial dependence of the potential in this case is consequently smaller than in the other prototype.

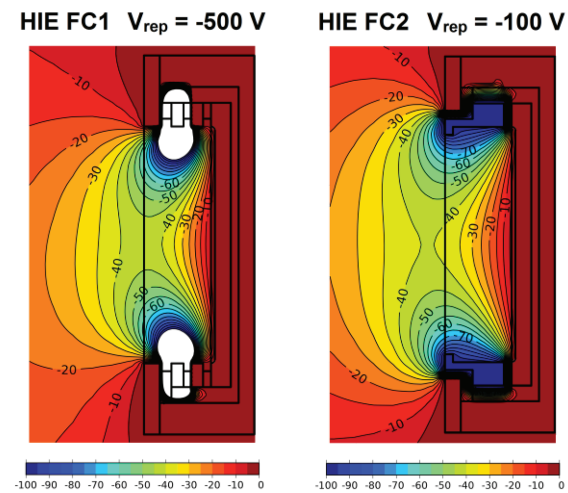

Figure 4: Electrostatic potential inside the HIE FC (V). Left: Prototype 1, biasing the repeller to -500 V. Right: Prototype 2, biasing the repeller to -100 V.

RESULTS AND DISCUSSION

In Figures 5, 6, and 7 we present the dependence of the current reading with the repelling potential for both prototypes and their comparison with a standard FC (REX FC), for beam energies of 0.30, 1.20 and 2.85 MeV/u. The results were acquired at different beam intensities (between 5 and 500 pA) and also collimating the beam with circular and linear apertures, and are shown normalized to the REX FC current reading obtained with V_{rep} = -60V for comparison purposes. No significant leakage currents were observed in the measurements with prototype 2 despite the lack of a guard ring.

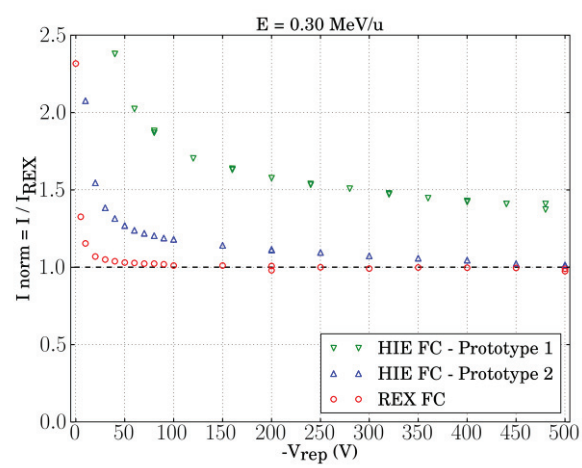

Figure 5: Normalized current as a function of the repeller potential for ions with energy E = 0.30 MeV/u.

For very low repelling values, the loss of electrons from the collector is translated into a current reading that is higher than the beam current. For the REX FC, the current reading shows a plateau for repelling potentials higher than -50 V. The presence of this plateau is an

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indication that the retention of low energy electrons is effective at this point. In the case of the HIE prototype 1, even for repelling voltages as high as -500 V, the current reading is higher than the total beam current, due to the fact that negative charges (the ion-induced emitted electrons) are being emitted from the collector and lost, increasing the (positive) current reading at the picoammeter. The excess of current determined with this prototype varies between 45 and 60% for repelling voltages as high as -500 V.

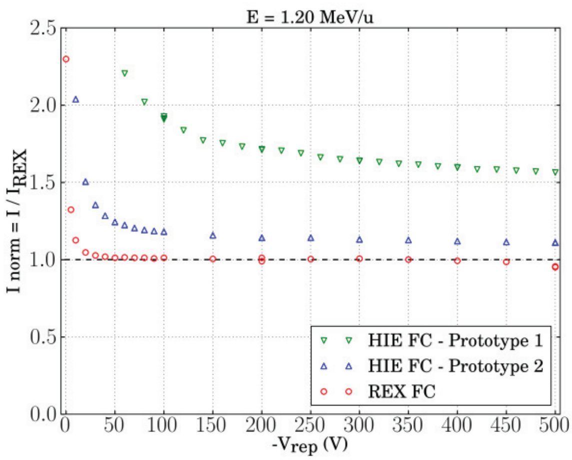

Figure 6: Normalized current as a function of the repeller potential for ions with energy E = 1.20 MeV/u.

In the case of the HIE prototype 2, the loss of electrons produces an excess of the current reading which is no higher than 25% for repelling potentials of about -100 V. The increased effectiveness for capturing the emitted electrons in prototype 2 is related with the more homogeneous potential barrier presented in the case of the longer repeller.

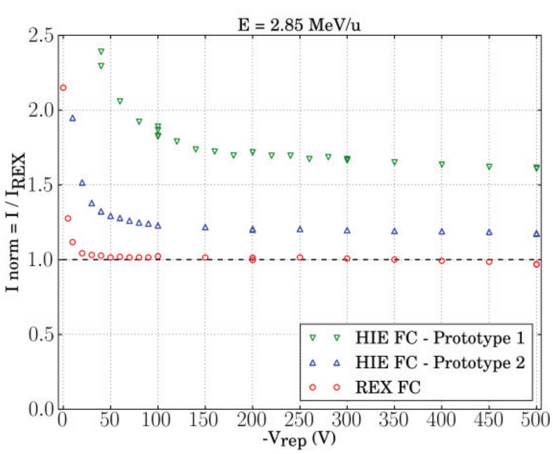

Figure 7: Normalized current as a function of the repeller potential for ions with energy E = 2.85 MeV/u.

Another biasing scheme has been considered, connecting the collector to a positive potential to attract the emitted electrons. That configuration has the advantage of a much more homogeneous potential barrier applied to the emitted electrons, as any electron emitted from the collector surface needs to overcome the same potential barrier to leave the Faraday cup. However, the extension of the electrostatic field outside the FC volume leads to a collection of any free electron that is present in the attracting field region, and therefore to an unsystematic decrease of the current reading. After a few experimental tests of this option, we decided to discard it as the uncertainties on the current values related with this effect can be very high and systematically increase with the applied potential to the collector.

CONCLUSIONS

We have designed and tested two different prototype Faraday cups for the HIE-ISOLDE project. An important characteristic of the needed cup is that its overall length is very reduced, leading to problems in the capture efficiency for emitted electrons due to the absence of signal cup walls.

The prototype that gives better results includes the largest possible repeller. For the energy range studied (between 0.30 and 2.85 MeV/u), a deviation of the current reading due to the loss of electrons from the collector is present, and can be up to 25% compared to the values obtained with a standard Faraday cup. This deviation has been determined for several beam shapes (using circular and linear collimators), and also for different beam intensities (between 5 and 500 pA), and can be corrected as it is a systematic effect.

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