CONCEPTUAL DESIGN FOR THE ARIEL 300 KEV ELECTRON GUN

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Abstract

The Advanced Rare Isotope Laboratory (ARIEL) at TRIUMF is a facility that will augment existing programs at ISAC [1]. ARIEL was funded in July 2010. Products from the complementary methods of proton-driven and bremsstrahlung-driven fission will be available for nuclear and materials science. Equipment for the photo-fission driver is the subject of this paper: a high-intensity electron beam provided by a high-voltage electron source (or e-gun) will be accelerated in a superconducting linear accelerator, and guided to a γ-ray convertor and actinide target assembly. The electron source is a 10 mA 300 keV thermionic gun, with a control grid for modulation of the beam. This paper describes the conceptual design of the gun, and highlights some of the progress made in the engineering design. First beam from the gun is anticipated in early 2012.

INTRODUCTION

The electron linear accelerator starts with a 10 MeV injector cryomodule. As originally conceived, a 100 keV bunched beam would be captured and accelerated to 0.5MeV in single-cell SRF cavities and then injected into a 9-cell TTF-style cavity. Given that the beam is delivered to a thick target, a thermionic gun provides sufficient brilliance. Bunching the beam at the gun obviates the need for a chopper and beam dump, which would be demanding at the average currents required. For those reasons a 100 keV DC gun was acquired from Jefferson Laboratory for the purpose of emittance characterization and the implementation of a 650 MHz modulation scheme similar to the one developed for the FELIX accelerator project [2].

Table 1: Source Specifications

Specification	Value
Beam Energy	300 keV
Average Current	10 mA
Modulation Frequency	650 MHz
Bunch Length	±16°-20° (at 650 MHz) FW
Bunch Charge	15.4 pC
Energy Spread	≤ ± 1 keV FW
Transverse Emittance	$\varepsilon_x = \varepsilon_y = 5\mu$m normalised ($1\sigma$)

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Subsequently, it was realized that the complicated SRF capture cavity system could be eliminated if the gun voltage was raised to 300 keV. At this energy, the longitudinal acceptance of the first cell of the 9-cell cavity becomes acceptable; and, moreover, some of the space-charge effect and phase-dependent RF focusing at entrance to the cavity are ameliorated. Essentially, 300 keV was chosen as a compromise between efficient matching to a β=v/c = 1 TESLA type cavity, and reliable high voltage operation. The specifications for the electron source are listed in Table 1.

GUN LAYOUT

The maximum voltage, which can be achieved in an electron source is limited by field emission from surfaces on negative high potential. In order to reduce the surface area of the electrode at high potential, an inverted anode and cathode structures compared to "classical" designs has been chosen, in which the anode electrode, rather than the cathode, penetrates far into the ceramic. A schematic of the gun can be seen in Figure 1 below.

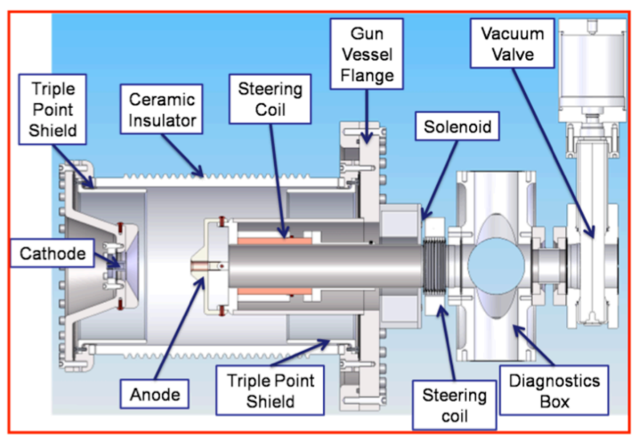

Figure 1: Layout of the electron gun components.

Due to the high voltages the gun assembly will be supported in a vessel with SF_6 isolation gas. Careful assessment of the electrode profile has begun, looking at two fundamental parameters, the electric field stresses (and the likelihood of breakdown) and the resultant output of the electron bunches from particle tracking. To avoid field emission in the gun, field gradients were limited to ≤ 10MV/m inside the vacuum envelope and ≤ 1MV/m within the insulation gas enclosure.

The ceramic is a long lead item, and has already been ordered from FRIATEC. The length of the ceramic assembly is 35cm with a 30 cm active ceramic length between the high opposing voltages. The anode to cathode gap is just 9.5 cm, meaning the anode penetrates nearly 20 cm inside the gun.

Optics analysis demonstrated that a focussing solenoid was required approximately 25 cm downstream of the anode aperture. Therefore the vacuum pumping and valve had to be pushed further downstream resulting in a reduced vacuum pumping speed. Assessment of the out-gassing rates of all the surfaces inside the gun and pumping speeds throughout the vessel indicate that we are still in a safe margin for achieving better than 10^{-9} Torr pressure.

At the triple point (metal, vacuum and ceramic), shields are being designed to provide the necessary protection. An electron emitted from the metal part of the junction could cascade down the inner surface of the ceramic, the current increasing as it goes under many iterations of secondary emission with coefficient greater than unity. This could lead to a flashover along the inner (vacuum) surface of the ceramic. The purpose of the shields is to reduce the electric field strength at the metal surface to inhibit field emission.

BEAM DYNAMICS

The electrostatic design of the gun adopts Pierce electrodes to provide focussing of the beam to compensate for divergence due to space charge and the cathode grid assembly. Since the electrodes are a source for field emission care was taken with a final peak electric field stress of around 7 MV/m on the surface, providing some margin of safety. The electric potential of the gun region was calculated with COMSOL and then transferred into GPT and ASTRA for beam tracking analysis.

For the analysis, the RF amplitude and the bias applied to the grid were adjusted to provide less than ±20° conduction angle and the electron beam properties were tracked 3cm after the anode aperture. The output from the GPT simulations are displayed in Figure 2 and results presented in Table 2.

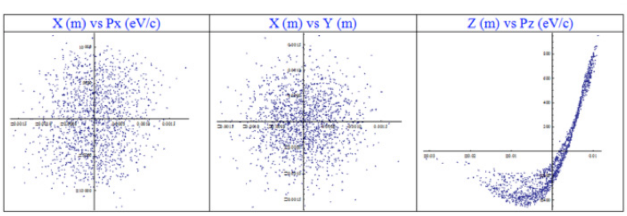

Figure 2: GPT Output 16 pC (±16° conduction angle).

Table 2: Key Output Parameters

16pC Macropulse	**Output** (±16°)
σx or σy	0.53 mm
σz	6.9 mm
σx'	7.43 mrad
εx^N or εy^N	4.85 mm-mrad

RF MODULATION

The electron source will utilise a gridded dispenser type cathode. The EIMAC Y-845 cathode has been chosen and a matching network has been developed to efficiently transfer RF power to the grid.

To determine the RF power requirements for the source, tests of the cathode on a 100 keV gun test stand were carried out. Such tests included measuring the transconductance of the grid, the matching of the RF to the grid and verifying modulation of the beam.

The transconductance of the EIMAC Y-845 cathode was measured to be 10 mA/V. In order to produce 10 mA average current with a ±16° conduction angle, a DC voltage of -420 V and 440 V RF volage on the grid are required. Calculations indicate that this can be achieved with approximately 9 Watts RF power deposited on the grid. Due to mismatches in the RF network up to 50 Watts of RF power will be required from the amplifier.

In order to minimise RF losses, and to ensure stable operation of the cathode, an RF circuit was designed to impedance match from the 50 Ω transmission line to the impedance of the cathode-grid structure.

A coaxial structure having a series of impedance steps, and a ¼ lambda stub were designed to provide power to the cathode heater, through the central terminal on the cathode structure.

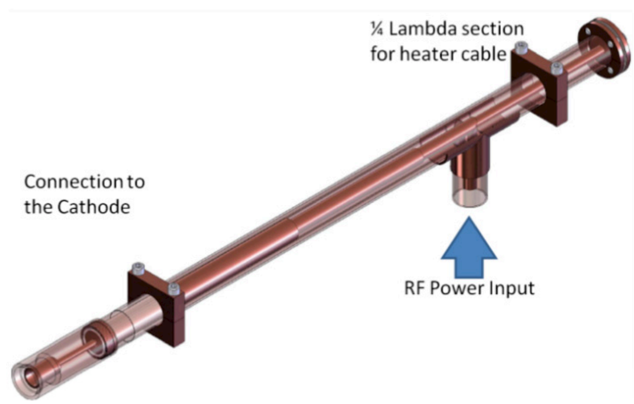

Figure 3: Sketch of the RF matching network.

HIGH VOLTAGE SERVICES

To reduce the required length of the ceramic, the gun vessel will be mounted in a tank of pressurised insulating gas. No final decision is required as yet on the gas, however allowance has been made to pressurise the gas to 2 atmospheres absolute. It has been proposed to use a gas mixture of 80% nitrogen and 20 % SF_6 to reduce the volume of SF_6 in the system. Literature [3] indicates that at 2 atms abs, the above mixture holds similar insulation properties as 1 atms abs. of pure SF_6.

No 300 kV RF transformers are available. Therefore most of the RF components as well as the grid bias and cathode heater power supply must be mounted on a high voltage platform inside the gun vessel. Figure 4 displays the current design for the gun vessel. Inside the tank, the central stack contains the RF amplifier, RF controls, heater and grid voltage power supplies. The ceramic insulator supporting the cathode can be seen 2/3 of the way down. Outside of the tank a diagnostics box and vacuum valve are shown. The high voltage platform is supported by insulated legs, with the platform a fixed distance from the gun vessel walls, which is at ground potential. The tank will open about the large seal, allowing access for servicing the gun and platform components.

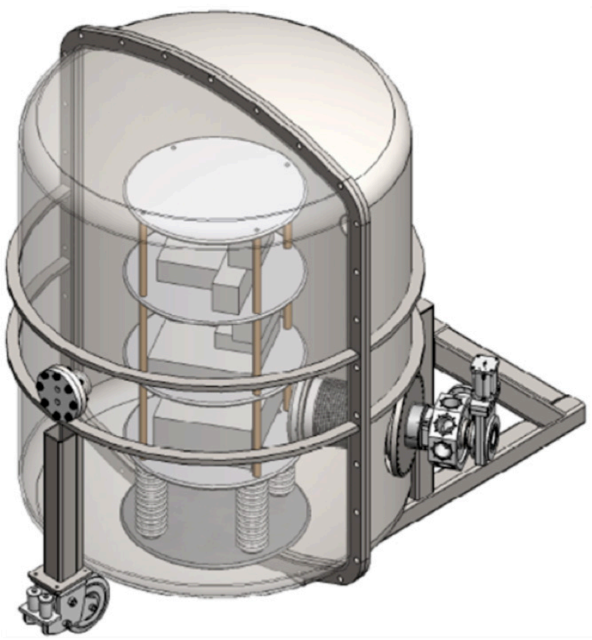

Figure 4: Schematic of the gun vessel.

The high voltage power supply has to produce 10mA of average beam current at 300 kV. To reduce field emission and breakdown in the gun, it will be required to condition the electron gun as high as 350 kV. Therefore the power supply had to be specified higher than its nominal operating level.

On the high voltage platform a number of components will require power, referenced to the high voltage. To provide sufficient power, a 2.3 kVA isolation transformer will be installed.

Following each vent of the electron gun vacuum envelope, it is required to bake out the gun and high voltage condition the electrode surfaces. During this operation, the high voltage will be applied through a conditioning resistor, that will minimise the current to a few hundred micro-amperes. This will protect the sensitive components being damaged from sparking, prior to operation.

The high voltage power supply, conditioning resistor, and isolation transformer will be located in a high voltage enclosure, protected by a number of interlocks to ensure safe access to the high voltage components.

Table 3: HVPS Specification

16pC Macropulse	**Output** (±16°)
Voltage	0 – 350 kV continuous
Average Current	> 10 mA
Ripple	0.05% rms
Stability	0.01%/deg. C
Repeatability	0.01% of set voltage

A high voltage feedthrough is required to transfer the 300 kV, 10 mA power for the cathode and the AC power for the platform components into the gun vessel.

CYCLOTRON FIELD COMPENSATION

The ARIEL Facility is in close proximity to the TRIUMF cyclotron, and due to this stray fields from the cyclotron magnet produce a near vertical magnetic field of 5 gauss around the region of the gun. Compensation of this field is required to reduce the on axis magnetic field to 0.1 gauss to reduce miss-steering of the low energy electron beam. Two measures have been adopted for this; first a Helmholtz coil is to be installed around the whole injector to cancel out the net field, and any local residual field resulting in beam miss-steering is corrected by coils placed along the anode barrel (outside of the vacuum envelope).

SUMMARY

The conceptual design was completed in December 2010, and following the review, the engineering design has commenced. Evaluation of the cathode on the 100 kV electron gun test stand was crucial in developing the RF requirements for the gun. Such testing ratified the RF power requirements and provided necessary confidence in the simulations. Procurement of key items such as the ceramic and the high voltage power supply is already underway.

REFERENCES

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