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OPERATION OF AN RF MODULATED ELECTRON SOURCE AT TRIUMF

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Abstract

ARIEL (Advanced Rare IsotopE Laboratory) at TRIUMF [1] will use a high-power electron beam to produce radioactive ion beams via photo-fission. The system has been designed to provide up to 10 mA of electrons at 30 MeV. The electron source delivers electron bunches with charge up to 16 pC at a repetition frequency of 650 MHz at 300 keV. The main components of the source are a gridded dispenser cathode (CPI –Y845) in an SF6 (sulphur hexafluoride) filled vessel and an in-air HV power supply. The beam is bunched by applying DC and RF fields to the grid. A macro pulse structure can be applied by additional low frequency modulation of the RF signal. This allows adjusting the average beam current by changing the duty factor of the macro pulsing. Unique features of the gun are its cathode/anode geometry to reduce field emission, and transmission of RF modulation via a dielectric (ceramic) waveguide through the SF6. The source has been installed and fully commissioned to a beam power up to 1 KW and tests with accelerated beams have been performed.

INTRODUCTION

The TRIUMF ARIEL Project

Within an ISOL (isotope production on line) facility rare isotopes are produced by bombarding solid targets with high energy particles. The ISAC facility at TRIUMF is using up to 100 µA of 480 MeV protons. One of the goals of the ARIEL (Advanced Rare IsotopE Laboratory) project is to complement this by photons induced fission in uranium targets. This photo-fission will be achieved by using Bremsstrahlung from 30 - 50 MeV electrons hitting a converter target in front of the production target. The project is aiming for a beam power of about 100 kW in a first stage and later up to 0.5 MW. This translates into an average current of 10 mA for continuous beam operation of the electron accelerator, a superconducting linac operating at 1.3 GHz.

Electron Source Requirements and Design

The minimum energy for the injection into the accelerator has been determined by beam optics simulations to be at 250 keV. Therefore, an operating voltage of 300 kV for the source has been chosen to stay well above this limit. The beam is modulated at half of the cavity frequency, i.e. 650 MHz. With an additional buncher in front of the first accelerating cavity a pulse length of <±16° of the RF phase at 650 MHz (137 ps) is required. In order to avoid beam losses during acceleration and beam transport to the target, the normalized emittance has to be ~< 5 µm. Additionally, the source should allow changing the duty factor of operation from 0.1% to 100% to accommodate beam tuning at low average beam power and an easy ramp up in power without changing the space charge loading of the accelerator cavities.

To fulfil the above requirements a source based on a thermionic dispenser cathode has been chosen. Such a cathode can operate stable and reliable over an extended period of time and doesn't require the extreme vacuum conditions of a photo cathode. When equipped with a grid in front of the cathode the beam can be modulated by applying a combination of DC and RF fields. Although the brightness which can be achieved with a thermionic cathode is lower, this is not a limiting factor for our application. For the measurements described below a cathode assembly Y-845 from CPI with an emitting area of 0.5 cm^2 was used

The principle of the modulation has been described already in [2]. The source is located on a 300 kV high voltage terminal inside a SF_6 filled vessel. More details of the installation and results from first tests are described in [3].

OPERATIONAL RESULTS

With the assumption of a linear dependence of the extracted current on the voltage applied in between the cathode and the grid, the charge per bunch Q emitted from the source can be described as

$$Q = \frac{g_{21}}{\pi f} U_{rf}\left(sin(\psi) - \psi\, cos(\psi)\right) \qquad (1)$$

with

$$\cos(\psi) = \frac{-U_b + U_C}{U_{rf}} \qquad (2)$$

and g_{21} being the transconductance, U_c the cut-off voltage, U_b the DC grid voltage, U_{rf} the Rf amplitude and f the RF frequency. ψ is the conduction angle. The pulse length of the electron bunch is given by 2ψ in units of the RF phase angle. g_{21} and U_c are parameters depending on the cathode material, geometry and the electrical field strength from the extraction voltage. They can be determined by measuring the electron current as function of a DC voltage applied to the grid. To limit the beam power rectangular pulses from a function generator with a maximum output voltage of +/- 10 V were applied to the grid. The measurement was done at several values for the extraction high voltage. Above 225 kV the electron emission could not be blocked in between the pulses with the available -10 V, mainly due to a nonlinearity at low voltages in the dependence of the electron current on the voltage at the grid. Therefore, the results had to be extrapolated to the desired operating voltage of 300 kV. Figures 1 and 2 show the dependence of g_{21} and U_c on the high voltage setting. Extrapolating the results to 300 kV leads to g_{21} = 23.4 +/- 0.3 mA/V and U_c = -8.3+/-2.1 V. For the cut-off voltage the value at 225 kV was not

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considered for the extrapolation as it is already affected by the nonlinear behaviour.

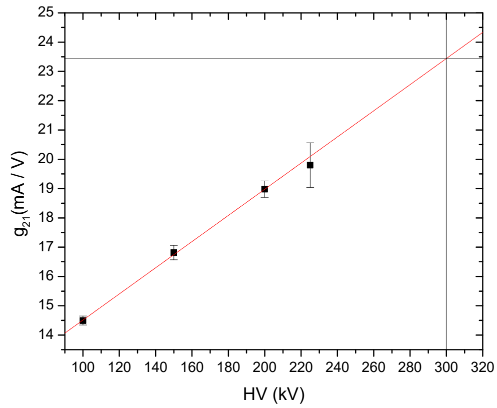

Figure 1: transconductance g_{21} as function of source high voltage.

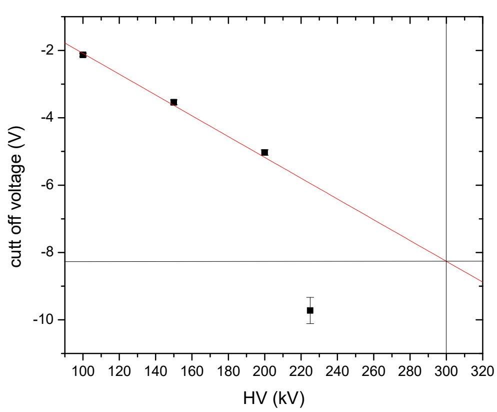

Figure 2: cut-off voltage U_c as function of source high voltage.

With those values the dependence of the average electron current on the conduction angle for different DC voltages at the grid can be calculated from Eq (1). The result is shown in Fig. 3. For the desired 10 mA of average current and +/- 16° pulse length an Rf amplitude of U_{rf} = 186 V and a DC bias voltage of U_b = -187 V is needed.

There are two main challenges for coupling RF power to the grid in front of the cathode; the impedance has to be matched and it has to be operated at the high potential of the cathode.

The dispenser Y-845 cathode assembly has a coaxial geometry, which allows an easy matching to apply RF - voltages to the grid. A coaxial transmission line has been used to match the cathode impedance of about 5 kΩ to the RF amplifier. The impedance change is done by changing

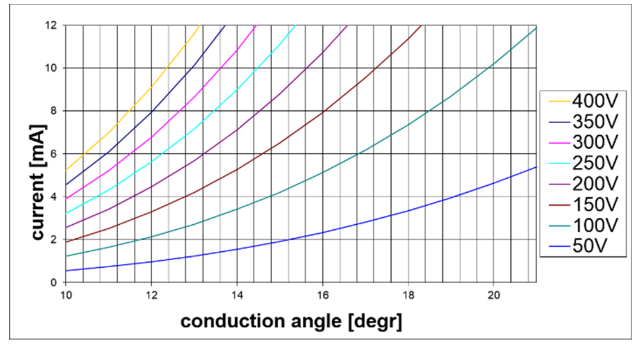

Figure 3: electron beam current as function of the conduction angel for different dc voltages at the grid.

the diameter of the inner RF conductor in 4 steps. The length of the last section can be adjusted for a fine tuning of the resonance frequency Details of the impedance matching are explained in another contribution to tis conference [4]. In order to reach an RF voltage of 200 V at the grid an RF power of about 4 W is needed. This value is for no beam current. With the additional load from the beam it will increase.

The speciality of the TRIUMF installation is the use of a dielectric ceramic waveguide to transport the RF power to the cathode assembly on the 300 kV high voltage terminal [4]. This allows operating the RF amplifier and controls on ground potential decoupled from the high voltage. The waveguide consists of a solid Al_2O_3 rod with diameter 105 mm and a length of 1.2 m. On both ends there are matching RF chokes to transport an electromagnetic wave through the ceramic. Simulations have been performed to maximize the RF power transmission and at the same time minimize the DC electric field strength for the high voltage isolation. Transmission losses for the RF at 650 MHz have been measured to be 1.7 dB [4].

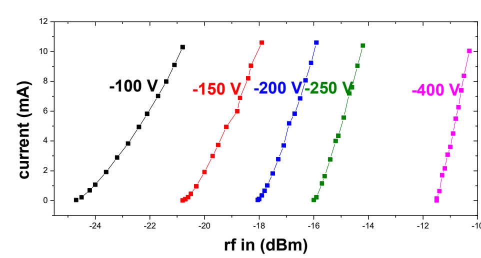

Figure 4: electron current as function of RF power (from the signal generator) for different settings of the DC grid voltage.

After installing the source at a low energy beam transport line, the principle of operation has been verified. Figure 4 shows the electron beam as function of the RF power for different DC bias voltages at the grid. It demonstrates that with the available RF power the required beam current can be reached. For an average electron current of 10 mA and a DC bias voltage at the cathode of 200 V less than 10 W output power from the amplifier are needed. Considering losses from the 60 m coaxial cable (1.46 dB)

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to the source, from the matching network and from the dielectric waveguide this value matches the estimation from above.

The transverse emittance of the beam has been measured with an Allison type emittance scanner [5]. Figure 5 shows the result as function of the average beam current for different DC voltages at the grid. The emittance increases with the beam current but also with the DC grid voltage. Both can be assigned to the effect of space charge. The average current is a measure of the total charge per bunch and the DC bias voltage determines the bunch length according to equation 1 and Fig.3.

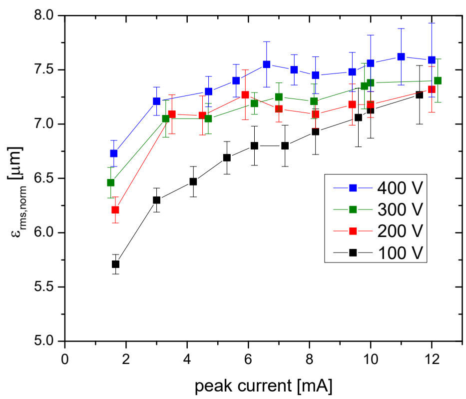

Figure 5: normalized rms transverse emittance as function of the average beam current for different settings of the DC grid voltages.

Another method, presently under development, of measuring the transverse emittance is beam imaging on a view screen as function of the focusing strength of a solenoid lens. It is limited to low beam power but offers a fast way of monitoring the correct functioning of the cathode during routine operation.

The momentum spread, and bunch length have been measured by bending the beam with a magnetic dipole into an diagnostics beam line. Directly after the bending magnet a deflecting cavity, which is synchronized with the beam modulation, deflects the beam perpendicular to the plane of the magnetic bender. The deflection depends on the phase difference between the cavity field and the beam modulation. Thus, analysing the beam on a view screen afterwards allows to determine both the momentum and phase spread of the beam. First measurements results are in good agreement with the predicted pulse length from Fig 3. For average intensities above 1 mA. At lower currents the pulses are slightly longer than predicted. In this regime the assumption of a linear dependence of the current on the grid voltage is not valid any more. The energy spread is <+/- 500 eV. More systematic measurements covering the parameter range for the source operation are needed for final conclusions on the longitudinal emittance.

The average beam intensity can be changed by applying a rectangular modulation with a specified duty factor at a low frequency on the RF signal. This will not change the beam pulses at the 650 MHz modulation and thus will keep space charge and bunch characteristics constant. The parameter range for this macrostructure is mainly limited by the ability to stabilize the 300 kV high voltage power supply with a changing load. The influence of the modulation on the beam has been investigated. The beam has been sent to a Faraday cup with a maximum rating of 100 W, which does not allow high duty factor operation at high peak current. The current measuring electronics is limited to a pulse length above 5 µs. With these limitations stable beam operation has been verified for modulation frequencies between 100 Hz and 15 kHz and duty factors 0.5% to 100% at low beam currents of up to 100 µA. At higher currents up to 10 mA the upper limit for the duty factor was determined by the total power which could be send to the Faraday cup. After those tests the source has been used over a several weeks for irradiation tests of target materials. During this test a beam current of up to 1.6 mA was used and a modulation frequency of 1 kHz. Stable operation was possible during the full operating range for the duty factor between 0.5% and 100%.

CONCLUSION

Operating parameters of the TRIUMF RF modulated thermionic electron source have been investigated and stable operation over a wide current range has been verified. The phase space of the beam has been measured. Although, the transversal emittance is slightly bigger than the original specifications, this is still acceptable for the accelerator and the planned applications. The longitudinal emittance is within the requirements, but more measurements over the entire parameter range are needed. The effect of the modulation on the energy spread of the beam remains to be determined.

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