EXPERIMENTAL EXPERIENCE WITH A THERMIONIC RF-GUN

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Abstract

An RF-gun structure developed at MAX-lab, and thus different from the most common BNL-structure, is in operation as a thermionic RF-gun at MAX-lab. The properties of the gun have been investigated. Especially aspects such as extractable energy range, emittance properties at various beam loading conditions and extracted current.

INTRODUCTION

Two RF-guns are installed in the new MAX-lab injector system [1]. The first has been in routine operation for over a year and is today the electron source of the laboratory, feeding a 120 MeV SLEDed linac. The second RF-gun is commissioned recently and will serve the finished 500 MeV injector with electrons. The performance of the operating gun has been investigated.

Gun

Both guns are of the same design [2], elaborated at MAX-lab. It is a thermionic RF-gun operating at 3 GHz, designed to produce electrons with a kinetic energy of 2.3 MeV. The gun has a ½+½+1 cell structure, as shown in fig. 1, to provide a decent field on the cathode and then some distance before the main accelerating cavity so that back bombardment on the cathode is reduced. The overall length of the gun is 100 mm, and the maximum inner radius is 40 mm. Immediately after the gun there are correction magnets in horizontal and vertical direction and a solenoid magnet. Thereafter follows an energy filter.

Energy filter

The task of the energy filter is to reduce the energy spread of the beam before it is further accelerated in a linac. It consists of two 60° dipoles with a fork in between, which scrapes away low energy electrons. Quadrupole doublets flank the dipoles on either side. In between the dipoles there is a focusing quadrupole, around which centre the energy filter is symmetric. The energy filter is made from two solid blocks of iron, with all the magnet positions fixed. Fig. 2 shows a sketch of the gun and energy filter setup.

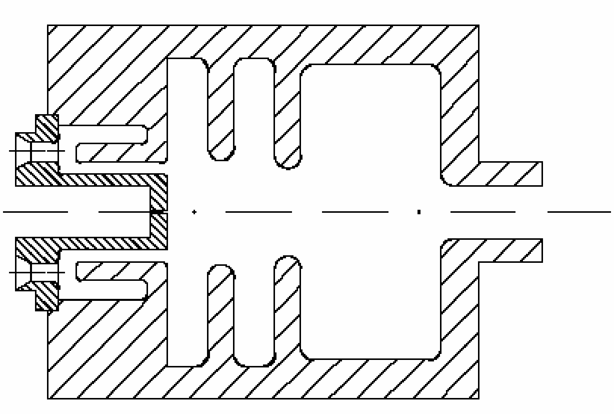

Fig. 1: Cross section of the gun.

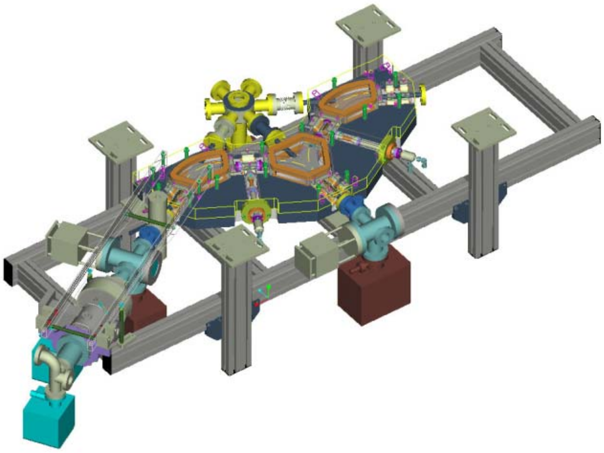

Fig. 2: The gun and energy filter.

Diagnostics

Several pick-ups and viewers are available for beam diagnostics. Inside the gun there is one pickup for electrical fields in each active cavity, where field strength and shape can be observed. Between the gun and the energy filter, just after the solenoid magnet, sits a current pickup (a Q-electrode) that gives the pulse length and current. Another Q-electrode is placed immediately after the energy filter, followed by a beam viewer; a YAG screen that can be inserted into the beam pipe and fluoresces when hit by electrons. The screen is then viewed with a camera connected to a computer with frame grabbing capability. Since the Q-electrodes were hit by rather more stray electrons than they seemed able to handle, especially the one after the energy filter, a current transformer positioned after the linac was used as well, to give a better idea of the amount of current that got through.

EXPECTED PERFORMANCE

The gun cavities have been simulated with SUPERFISH and the electron beam behaviour with PARMELA using the fields resulting from the cavity simulations [3]. Some results for the beam core assuming 600 mA current immediately after the gun are shown in table 1, while table 2 shows some data for the total beam after the energy filter.

Table 1: Performance of the gun, from simulations.

Beam kinetic energy	2.3	MeV
dE	18	keV
ε	1.8	μmrad
ε, norm	9.8	μmrad

Table 2: Beam parameters after the energy filter.

Length (total)	0.56	mm
dE	110	keV
ε_x	1.8	μmrad
ε_x, norm	9.8	μmrad
ε_y	2.5	μmrad
ε_y, norm	13.6	μmrad

Emittance

From the gun the beam is round, with equal emittance in both vertical and horizontal direction. The energy filter distorts the symmetry of the beam and the vertical emittance grows.

Current

The gun should be able to produce a current of at least 600 mA. However, this is much more than is needed for regular operation. Roughly half of the current from the gun is expected to be filtered out in the energy filter.

Beam Loading & Energy

A significant beam loading is expected in the gun, even at lower currents than the design value. For that reason the gun is over coupled so that it is self stabilising while emitting electrons. The maximum kinetic energy the gun is designed to deliver is 2.3 MeV, but we are limited to a lower energy by the circulators in the RF transmission line.

OBSERVED PERFORMANCE

The measurements were done for different temperatures on the cathode, and with various excitations of the gun.

Emittance

By measuring the width of the beam, σ, at the screen for a number of settings of the last quadrupole in the energy filter the horizontal Twiss parameters can be determined before this magnet.

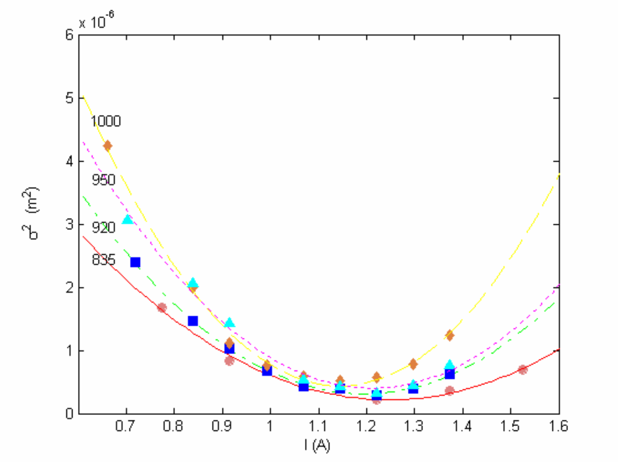

Fig. 3: Measured values of σ^2 as a function of the current, I, to the quadrupole for different temperatures on the cathode, along with quadratic fits.

A good agreement with the quadratic relation of σ^2 to the quadrupole current expected from the thin lens approximation, eq.1, was found, as shown in figure 3.

$$\sigma^2 \approx \varepsilon\beta = \varepsilon\left((1-\frac{l}{f})^2\beta_0 - 2l(1-\frac{l}{f})\alpha_0 + l^2\gamma_0\right) \qquad (1)$$

The focusing factor 1/f in eq.1 is proportional to the current in the quadrupole. In fig. 4 and table 3 the emittance is displayed as a function of the temperature on the cathode. At lower temperatures the cathode emits less electrons, resulting in less blow-up of the beam due to space charge effects, which in turn means a lower emittance. In fig. 5 emittance and beam current are plotted as functions of the energy due to different excitations of the gun.

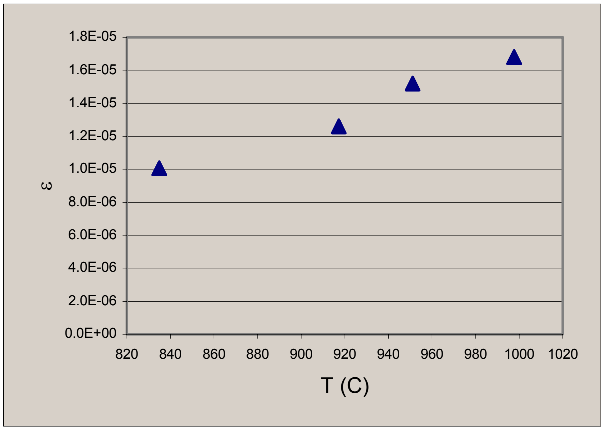

Fig. 4: Emittance as a function of cathode temperature.

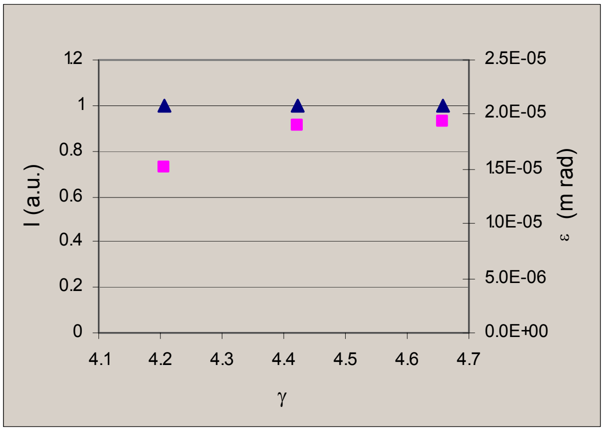

Fig. 5: Current (triangles) and emittance (squares) as functions of beam energy.

That the emittance goes down with lower energy is unexpected. A possible explanation might be that the focusing properties of the gun vary more with energy than do space charge effects.

Since the vertical emittance is extremely sensitive to the optics in the filter we didn't bother to measure it.

Current

The amount of current getting out of the gun is dependent on the cathode temperature. There is some threshold temperature below which no electrons are emitted from the cathode and likely some temperature above which saturation occurs. Our measurements were done inside this window, although the lower limit was approached and can be extrapolated from fig. 6 to about 720 °C. At the q-electrode after the gun some relative relations of the current can be measured, and are plotted as a function of cathode temperature in fig. 6, normalised to the current we have at operational temperature (950°C). In fig. 5 can be seen that the current is independent of the energy of the beam. Although the absolute values received here might be a bit dubious, some are given in table 3.

Beam Loading & Energy

By changing the temperature of the cathode, it can be seen in several ways that the beam loading change as well. Inside the gun the amplitude of the fields decrease with increased temperature, as more electrons are emitted and take from the field power. At the same time it can be seen at the q-electrode that the current grows, and in the energy filter the dipole strength has to be decreased, indicating lower energy as a result of the lower fields in the gun. The energy and current behaviours are shown in fig. 6, as well as given in table 3.

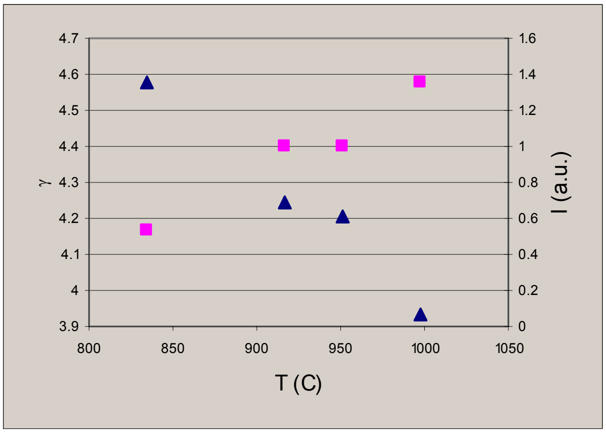

Fig. 6: Energy (triangles) and current (normalised to the current at operation, squares) from the gun as functions of cathode temperature.

Table 3: Measured beam parameters. The values of the current are uncalibrated.

Cathode temperature (°C)	Normalised emittance (μmrad)	Kinetic energy (MeV)	Beam current (mA)
835	10.1	1.83	70
920	12.6	1.66	130
950	15.2	1.64	130
1000	16.8	1.50	170

SUMMARY

The observed performance corresponds well with the expected for all measured parameters, except the emittance which is too high. Due to somewhat insufficient diagnostics some parameters were hard to quantify absolutely. Nevertheless relative comparisons are the more important, and these tests have been fruitful gaining experimental experience in advance of adapting the thermionic RF-gun to a photo cathode [4].

REFERENCES

[1] S. Werin et al, *The new injector and storage ring for MAX-lab*, PAC 99, p. 2945

[2] B. Anderberg et al, *A new 3 GHz RF-gun structure for MAX-lab*, EPAC 00, p. 1684

[3] B. Anderberg et al, *Project Report,* http://www.maxlab.lu.se/

[4] S. Werin et al, *Adaption of an RF-Gun from Thermionic to Photo Cathode,* these proceedings