

Beam Emittance Measurement from CERN Thermionic Guns

O. Kester *, R. Rao*, L. Rinolfi, CERN, CH-1211 Geneva 23

Abstract

In the LEP Injector Linacs (LIL) a thermionic gun provides electron beams with different peak intensities at an energy of 80 keV. In 1990 a new front-end was designed and installed [1]. The beam emittances were estimated from the EGUN programme. Since the gun is of triode type, the main contribution to the emittance comes from the grid. The simulation programme does not model the real geometry by assuming a cylindrical symmetry, while the grid does not have such symmetry. A Gun Test Facility (GTF), allowing emittance measurements, based on the 3-gradients-method [2], was installed. This paper presents the experimental results.

1 INTRODUCTION

For various reasons, it is often necessary to evaluate the transverse beam characteristics at the exit of thermionic guns. The EGUN programme [3] allows one to simulate beam dynamics in such guns. However, this code was developed for beams having rotational symmetry and is not suited for our thermionic guns, where the grid has a square mesh.

In the framework of upgrading the LIL front-end, a facility was foreseen to test gun modulators. Later on, a beam test line was designed and installed downstream of the gun [4]. It allows us to perform beam measurements under various conditions. The beam energy, the pulse length, and the peak current can be varied from 10 keV to 100 keV, 5 ns to 50 ns, and 0 to 15 A, respectively. The repetition rate is 100 Hz.

Emittance measurements are done with a Faraday cup which can be moved in the two transverse directions and which is situated close to the focal plane of the last solenoid. In this paper, the emittance measurements are given for an energy of 80 keV and a pulse length of 50 ns.

2 RECALL OF THE BASIC THEORY

The volume occupied by the 6-dimensional phase space is invariant. Here the time structure of the beam is kept constant and only the transverse planes are considered. For the present configuration, the horizontal emittance ϵ_x is assumed to be equal to the vertical emittance ϵ_y . Although a solenoid focuses a non-relativistic beam in both transverse planes x and y , the measured emittance is independent of the rotation given by the solenoid. Hence,

it is sufficient to consider one transverse plane. With the Twiss parameters α, β, γ , the ellipse equation is given by [5]

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \epsilon \quad (1)$$

where

$$\beta\gamma = 1 + \alpha^2 \quad (2)$$

In our case, a thin solenoid is used. Its length l_s is negligible compared to the following drift length l . Under these conditions, the transfer matrix of one solenoid followed by one drift is (for one plane)

$$M_{d-s} = M_d M_s = \begin{pmatrix} 1 - lq & l \\ -q & 1 \end{pmatrix}, \quad (3)$$

where l is the drift length downstream of the solenoid and $q = Kl_s$; K is the strength of the solenoid. The Twiss parameters are transferred from one point z_0 (source) to another one z_1 (measurement) according to the following equation

$$\nu = M_{d-s} \nu_0 M_{d-s}^T \quad (4)$$

where

$$\nu = \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

Developing the equation (4), one obtains

$$\begin{aligned} \beta &= \beta_0(1 - lq)^2 - 2\alpha_0 l(1 - lq) + \gamma_0 l^2 \\ \alpha &= \beta_0 q(1 - lq) + \alpha_0(1 - 2lq) - \gamma_0 l \\ \gamma &= \beta_0 q^2 + 2\alpha_0 q + \gamma_0 \end{aligned} \quad (5)$$

The β value and the beam radius σ are linked by the relationship $\sigma^2 = \epsilon\beta$. With three currents in the solenoid, we measure three σ values, and from the first equation of (5), we can derive the following system of equations

$$\begin{pmatrix} \sigma_1^2 \\ \sigma_2^2 \\ \sigma_3^2 \end{pmatrix} = \begin{pmatrix} (1 - lq_1)^2 & -2l(1 - lq_1) & l^2 \\ (1 - lq_2)^2 & -2l(1 - lq_2) & l^2 \\ (1 - lq_3)^2 & -2l(1 - lq_3) & l^2 \end{pmatrix} \begin{pmatrix} \epsilon\beta_0 \\ \epsilon\alpha_0 \\ \epsilon\gamma_0 \end{pmatrix} \quad (6)$$

Equation (2) is multiplied by ϵ^2 and gives

$$\epsilon = \sqrt{(\epsilon\gamma_0)(\epsilon\beta_0) - (\epsilon^2\alpha_0^2)} \quad (7)$$

By virtue of equations (6) and (7) the beam emittance can be deduced. It is also possible to find out the Twiss parameters at the source z_0 . This non-destructive method is an efficient way to get a good measurement of the emittance, without any knowledge of the particle distribution in the beam.

*Institute for Applied Physics, University of Frankfurt

3 EXPERIMENTAL SET-UP FOR PROFILE MEASUREMENT

Fig. 1 shows the layout of the GTF. For given conditions of the e^- beam, the Faraday cup (FCU) scans the beam spot. The FCU has a diameter equal to 5 mm. Normally the measurement is repeated three times with three different currents in the solenoid SNF 4.

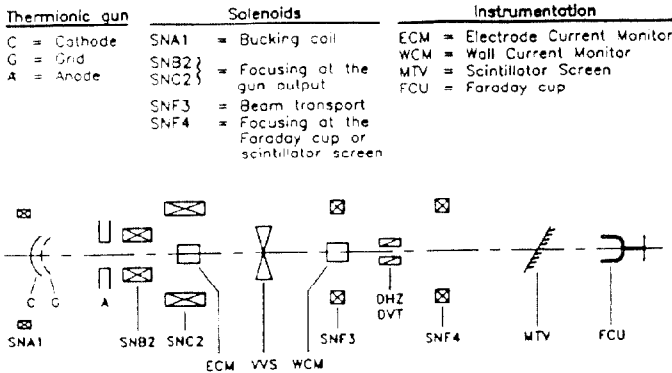


Figure 1: Layout of the Gun Test Facility (GTF)

From the profile measurement, the radius of the beam can be determined in the plane where the Faraday cup is moved. The beam radius σ is defined by the half width half maximum of the beam intensity (HWHM). The measuring logic is shown in Fig. 2.

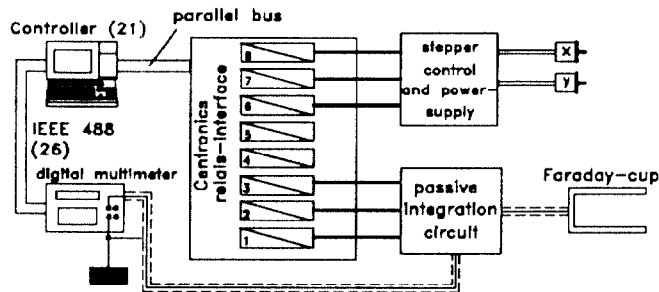


Figure 2: Scheme of the measurement devices and control lines

A PC computer controls a digital multimeter and a centronics interface. A passive integrator is connected to the digital voltmeter which is controlled by the IEEE488 bus. The integrator and stepping-motors are controlled by a relay-interface driven by the controller via the parallel bus. The Faraday cup (FCU) is connected to the integrator with a coaxial cable. The detector is moved over the whole beam in both directions, x and y , in constant steps of 1 mm, with motor driven micrometer screws. The part of the beam, which is collected by the FCU, is used to charge a capacitor. A complete scan is composed of 4 cycles:

- a) Cycle 1: Positioning the FCU (1.5 to 4 s)
- b) Cycle 2: Charging the FCU (1 s)
- c) Cycle 3: Measuring the voltage at the FCU (100 ms with a time constant of the integrator of 20 s)

d) Cycle 4: Discharging the FCU (200 ms).

When a complete scan is accomplished, a computer programme draws the beam profile, measures the sigma of the beam in both transverse planes x and y and calculates the corresponding emittances.

4 EXPERIMENTAL RESULTS

Figure 3 shows the measured beam profile for a beam of 1 A. It is approximately cylindrical.

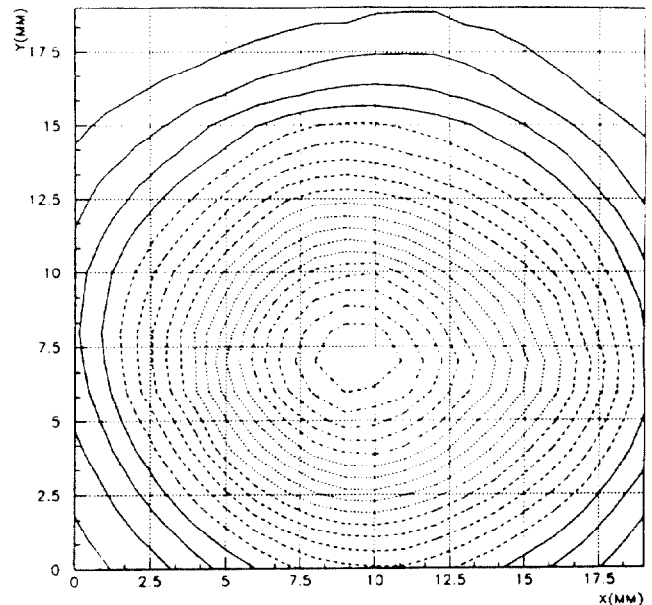


Figure 3: Plot of isolines for a beam of 1 A

A 3-D plot is given in Figure 4. One can observe that the distribution is roughly gaussian.

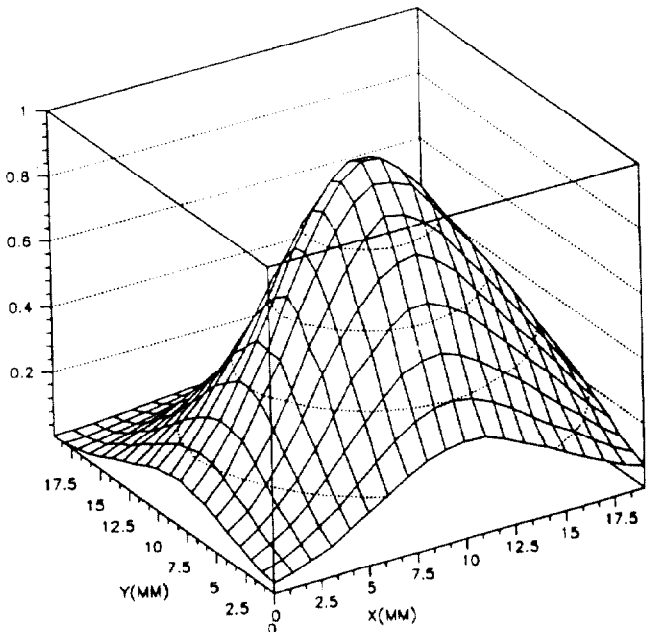


Figure 4: 3-D plot of the beam distribution

The beam radius σ is determined at the isoline which contains, assuming a gaussian distribution, 85 % of the beam. The focal strength q is calculated by the expression [4]

$$q = \frac{I_{coil}^2}{200.9} \text{ (m}^{-1}\text{)} \quad (8)$$

The Faraday cup is installed at a distance from the last solenoid of $l = 571$ mm.

Figure 5 shows the measured beam emittances versus the beam current. With a beam current of 1 A the measured emittance is around 120 mm.mrad. With an error of 3 % on the σ , the calculated error on the emittance [6] is $\Delta\epsilon \approx 10$ mm.mrad. The normalized emittance becomes $\epsilon_n \approx 70$ mm.mrad for our gun energy where $\beta\gamma = 0.581$. As discussed above the Twiss parameters can be calculated at the source. Under the same conditions, the following values are found out: $\alpha_0 = -3.7$, $\beta_0 = 1.1 \text{ m.rad}^{-1}$, $\gamma_0 = 13.1 \text{ m}^{-1} \text{.rad}$.

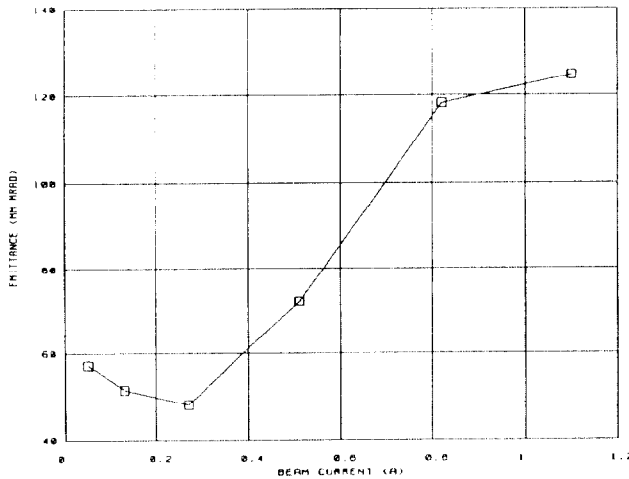


Figure 5: Beam emittances versus beam current

It is interesting to note that according to simulations [6], the same behavior for the beam emittance blow-up is obtained. For a beam current of 1 A the calculated emittance is around 100 mm.mrad. However, as already mentioned, the simulations take into account only cylindrical symmetry.

Another experimental measurement was done, when the grid image was produced at the Faraday cup for a given optics. Figure 6 displays the distribution obtained. The analysis for this case is outside the scope of this paper.

5 CONCLUSION

With the CERN Gun Test Facility, it will be possible to measure the beam characteristics under various conditions (peak currents, energy, pulse lengths,...). The measured beam emittances can be used as reliable inputs for simulation programmes which are needed to design the optics downstream of the thermionic guns, including grids with no symmetry.

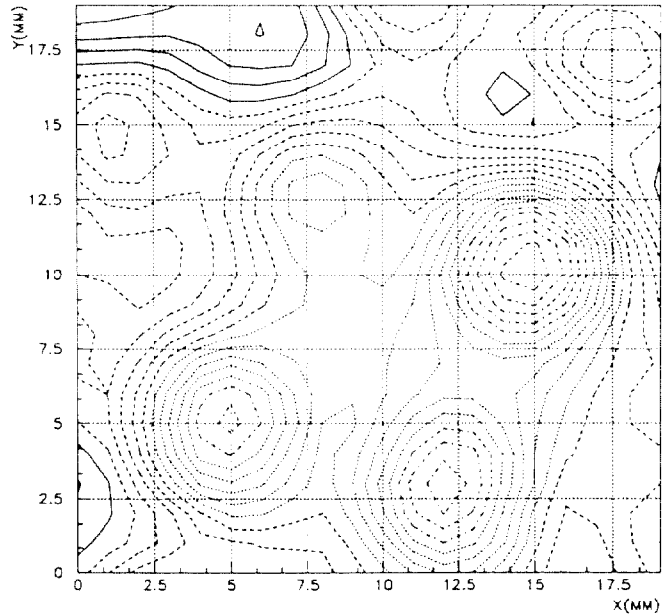


Figure 6: 2-D distribution plot for the grid image

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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