FR8600434

COMMISSARIAT A L'ENERGIE ATOMIQUE

CENTRE D'ETUDES NUCLEAIRES DE SACLAY
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CEA-CONF -- 7961

L4

Rapport DPhN/Saclay n°2270 05/1985

A DEVICE FOR ELECTRON GUN EMITTANCE MEASUREMENT

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Communication présentée à : Particle accelerator conference
Vancouver (Canada)
13-15 May 1985

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Introduction

In order to improve the final emittance of the beam delivered by the ALS electron linac [1] a new gun is going to be installed. To measure its emittance and evaluate the contribution of different factors to emittance growth we have developed an emittance measurement device.

We describe the experimental and mathematical procedure we have followed, and give some results of measurements.

Principle of the method [2]

The size of the beam is measured for different settings of a magnetic lens. A computer program solving the envelope K-V equation, finds the three parameters of the transverse phase space ellipse at the exit of the gun which fit the experimental data.

The use of cylindrical iron magnetic lenses implies a limitation of the method to beams having a symmetry of revolution.

Experimental apparatus

The assembly is represented in Fig. 1. After the gun flange it comprises two magnetic lenses (L1, L2), deviation coils (S), a system of 6 wires (W) in a plan perpendicular to the beam axis, the arrangement of which is represented on Fig. 2. If the beam is deviated horizontally, the vertical central wire is used to scan the beam profile, by measuring the intercepted beam current. The right and left wires, situated 5 mm apart, from the central one, are used to calibrate the deviation coils, so that their current can be converted into beam displacement in the wires plan. Of course, the same operation can be repeated in the other direction as a check measurement.

The wires are made of cooper-berylium alloy and have a diameter of 50 µ. They are stretched on a frame cut out of a PTFE-glass card, suited for high vacuum. The beam finally is collected in a graphite Faraday cup (F). Its distance to the wires is 10 cm in order to prevent them from collecting secondary electrons.

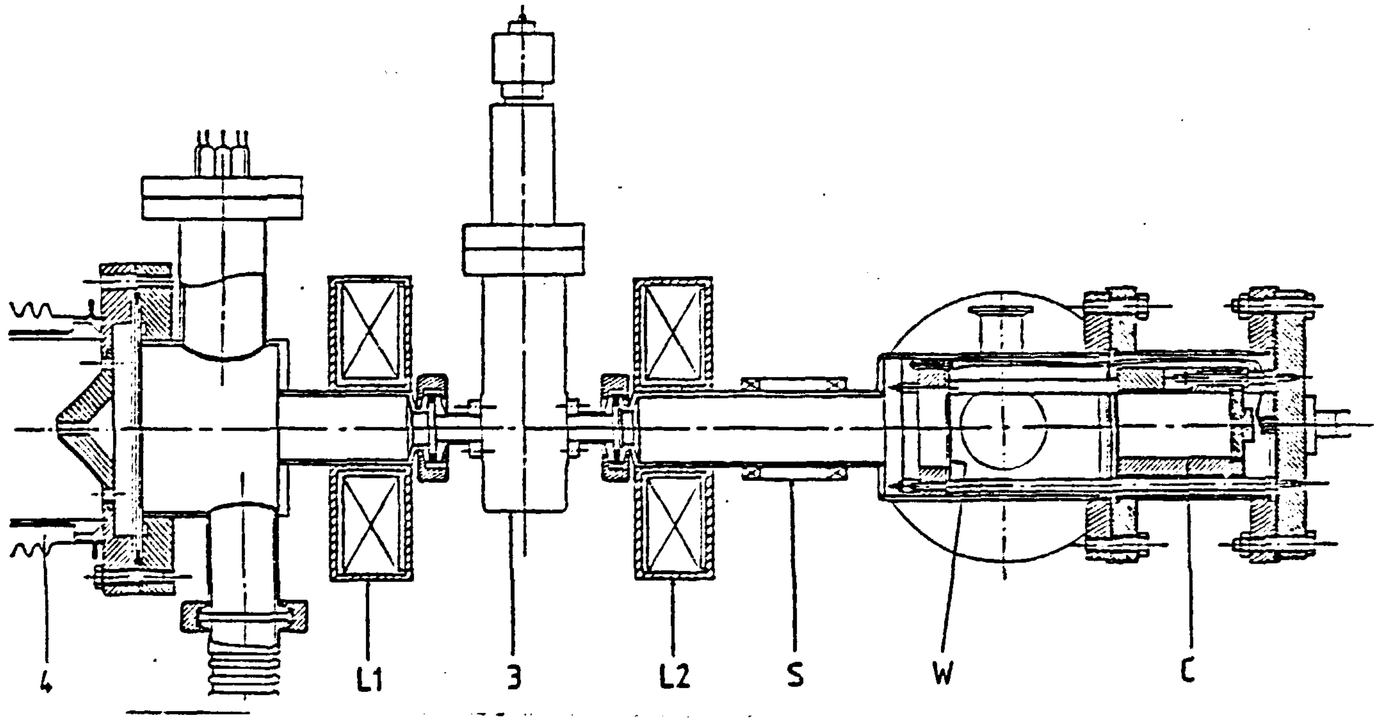

Figure 1. Emmittance measurement set-up

L1, L2 : Magnetic lenses - S : Steering coil - W : Wires plan -
C : Faraday cup - 1 : Pumping flange - 2 : Vacuum gage port -
3 : Vacuum valve - 4 : Gun -

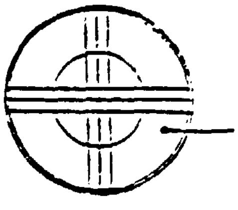

Fig. 2 Schematic of wires arrangement.

Measurement procedure

The first lens L1 is set-up to obtain a good transmission of the beam into the Faraday cup. Its setting is then left constant. The L2 lens, is then given N different settings through the range of currents that ensures a total transmission to the Faraday cup. For each L2 setting the beam radius is measured by scanning the beam on the central wire with the deviation coil. We use typically N = 10 to 15

Emittance calculation procedure

Emittance calculation is then performed by running a FORTRAN program on a NORSK DATA Nord-500, 32 bit computer. The procedure uses integration of the K-V envelope equation :

$$\frac{d^2r}{dz^2} + K(z)r - \frac{h}{r} - \frac{\epsilon^2}{r^3} = 0 \qquad (1)$$

where $K(z) = (qB/2m_0\, c\beta\gamma)^2$, $B = B(z)$ = magnetic field on the axis. $h = eI/2\pi\, m_0\, \epsilon_0(\beta\gamma c)^3$, I = beam current. $\epsilon = 1/\pi$ × beam emittance.

The equation is integrated successively for the magnetic fields corresponding to the N different settings of the L2 lens.

The magnetic field is computed either by a cubic SPLINE interpolation routine from measured data, or from a fitted Gaussian function :

$$B(z) = B_0\, e^{-\frac{z^2}{2a^2}}$$

The integration routine is given an origin abscissa z_0 corresponding to the location where the emittance ellipse parameters are to be computed and initial values ϵ, r, θ respectively for emittance, enveloppe radius, envelope angle with axis. The integration can then be performed and beam radius calculated at the abscissa corresponding to the location where they have been experimentally measured.

Once the N beam radius have been calculated they can be compared to the experimental one by calculating the function :

$$\chi^2 = \sum_1^N \frac{(R_{exp} - R_{calc})^2}{R_{calc}}$$

N number of L2 settings
R_{exp} experimental beam radius
R_{calc} calculated beam radius.

A routine using a "direct search method" then minimizes the χ^2 function by varying the three parameters ϵ, r, θ. The final values of these parameters allow the knowledge of the emittance ellipse : the α and β coefficients of the ellipse are related to ϵ, r, θ by :

$$\beta = r^2/\epsilon \qquad \alpha = -\sqrt{\frac{r\theta}{\epsilon}}$$

Results are displayed as shown on figs. 3 and 4. Typical CPU time is about 1 minute.

Measurement of rms parameters

The beam radius measurement described before uses the "base" of the beam profile which is often not very accurately defined. The emittance obtained this way is therefore the "marginal" emittance i.e. the emittance that contains nearly 100 % of beam current. This figure is pessimistic because the outer part of the beam can be large and carry very low current. It is therefore useful to determine the rms emittance. This requires the knowledge of rms beam radius.

For that, we still use the same device, plot the total beam profile, for each lens setting, and calculate their standard deviation. We assume a Gaussian distribution for the beam. The particle density in real space is then :

$$j = \frac{1}{2\pi\sigma^2}\, e^{-\frac{x^2 + y^2}{2\sigma^2}}$$

The current intercepted by a vertical wire at abscissa x is then :

$$I(x) = \int_{-\infty}^{+\infty} j\, dy = \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{x^2}{2\sigma^2}}$$

The standard deviation of the measured profile gives then the σ of the beam.

The use of K-V equation (1) is still possible with rms radius and rms emittance [3]. Instead of the total beam current I in the space charge term one has to use the fraction of the current that would be responsible for the space charge force experienced by electrons at a distance σ from the axis. For a Gaussian charge distribution, this fraction is : $1 - e^{-0.5}$ ≈ [illegible]

Method testing

In order to test the method validity, we have first measured the emittance of a beam after it passed through a set of two circular apertures of known diameters and distance. We took, for example, two 2 mm diameter holes distant 100 mm one from the other, thus defining an acceptance of 10 mm·mrd. The first aperture was in fact set to be the anode hole itself. The gun beam was known to be such that the acceptance was filled up. The z_0 abscissa where the computer calculates the envelope parameters was that of the second aperture. This way, the beam radius had to be found equal to the hole radius and the emittance equal to the acceptance of the 2 holes.

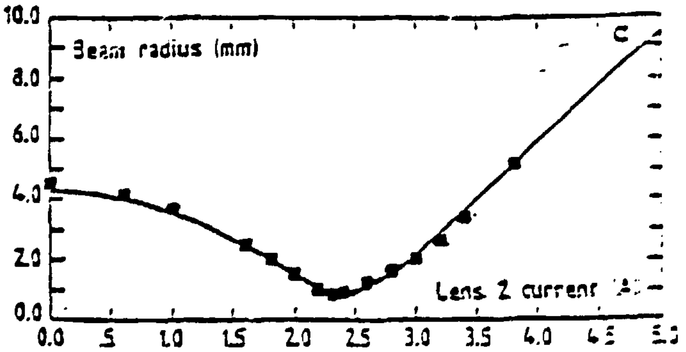

Fig. 3 Computer generated fit of the experimental radius measurement - The beam used for this measurement has been defined by a set of two apertures of 2 mm diameter, separated by 100 mm.

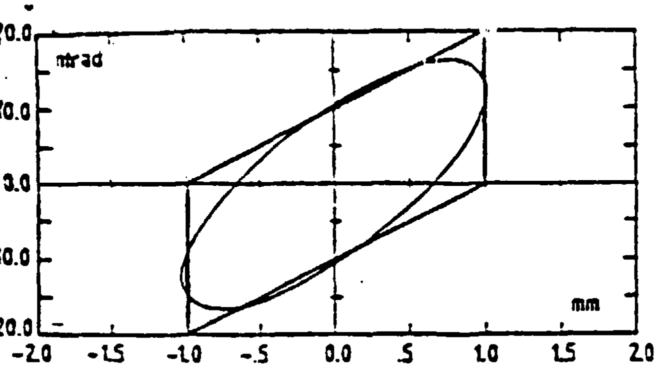

Fig. 4 Ellipse beam emittance compared to the acceptance parallelogram of two 2 mm diameter holes separated by 100 mm used to define it.

Results of this test are represented on fig. 3. On fig. 4 the parallelogram is the acceptance of the two apertures and the ellipse is the beam emittance found.

Measurement on the new electron gun

A new electron gun has been purchased from Hermosa Electronics [4] to replace the old original one that still worked with a direct emitting cathode. The new one has a dispenser cathode with an emitting area of 0.5 cm^2. Its operating range is 40 to 50 kV and up to 100 mA current. This gun is controlled by the grid voltage. So, its emittance is expected to depend on its output current : it is to be the lowest when the grid voltage has the same value than the equipotential it materializes in the equivalent diode gun [5].

Table I show results of measurements performed for three output-currents.

Table I

Marginal and rms emittances measured on the ALS new gun.

gun current (mA)	Marginal emittance (π.mm.mrd)	rms emittance (π.mm.mrd)
20	70	13,7
50	65	11,6
100	58	7,4

The measured emittance can be considered as the resultant of three terms :

$$\varepsilon^2 = \varepsilon_a^2 + \varepsilon_c^2 + \varepsilon_g^2.$$

ε_a is the gun aberration term. From computer runs performed with the Slac Electron Trajectory Program we know that $\varepsilon_a = 3\pi$ mm-mrd. On another hand we can calculate $\varepsilon_c = \pi r_c \cdot \sqrt{\frac{kT}{m_0c^2}} \times \frac{1}{\beta\gamma}$ with $r_c = 4$ mm (cathode radius), kT = 0.12 eV (cathode temperature), $\beta\gamma = 0.4$ for 40 kV gun high voltage. One finds $\varepsilon_c = 5\pi$ mm-mrd.

It therefore appears that the measured emittances for i = 20 mA and i = 50 mA result mainly of the grid term. For I = 100 mA the grid term reduces to $\varepsilon_g = 4{,}5\pi$ mm-mrd.

Apparatus computerization

Computerization of the experimental procedure makes measurements faster and more reliable by eliminating operator errors.

We have used for doing this EUROMAK standard electronic modules built by Microprocess [6]. It is an 8-bits bus, intended for instrumentation interfacing. A master module using a Motorola 6809 chip has been used. It has been programmed in assembly language. Operator interface comprises console, keyboard and printer.

We are now in the process of improving this system by using an autonomous VME crate and a Motorola 68000 controller card, a hard-disk unit and a graphic console. It will be programmed in Fortran. Profile runs calculation can be made on line. Results will be stored on a floppy disk and then transported to the NORD-500 computer

Conclusion

A method has been described to measure the three parameters of the emittance ellipse of an electron beam having a symmetry of revolution. Its advantages over other methods is that it takes space charge into account. The experimental device is simple and in particular has no mechanical part to be moved through the chamber wall.

References

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