

COMPUTER ASSISTED BEAM CHARACTERIZATION AT AIRIX FACILITY

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Abstract

AIRIX is a high current accelerator designed for flash X-ray radiography. The electron beam produced into a vacuum diode (2 kA, 3.5 MV to 3.8 MV, 60 ns) is extracted from a velvet cold cathode. For a complete beam characterization, at the diode output, a set of beam transport data is required. Part of those parameters can be experimentally obtained, but others, the transverse beam sizes, are unfortunately not measured. The TRAJENV [1-3] code is designed to simulate beam transport [4-5]. The code is coupled with the MINUIT [6-7] minimization library and it computes the unknown beam parameters at the diode output. In this paper, we propose to describe both experimental and theoretical approaches leading to the full beam characterization at the diode output.

THE BEAM PARAMETERS

For a complete beam characterisation, downstream the diode output, the following set of data is required: the primary beam current intensity ($I^{(0)}$), the primary beam energy ($E^{(0)}$), the 2D transverse root mean square (rms) beam sizes (X_{rms} , Y_{rms}), the 2D transverse rms beam sizes ($X_{rms}^{(0)}$, $Y_{rms}^{(0)}$), the 2D rms beam divergence ($X'^{(0)}$, $Y'^{(0)}$), as well as the 2D beam emittance ($\epsilon_x^{(0)}$, $\epsilon_y^{(0)}$) respectively in the phase space (xx') and (yy').

EXPERIMENTAL PARAMETERS

The experimentally beam transport parameters are given as well by electrical sensors located into the beam line (for the beam current I) by time resolved energy spread measurements (for E), as well as by a classical beam imaging set-up (for X_{rms}^* , Y_{rms}^*).

The figure 1 shows the linear relation between the beam current and the beam energy.

For the mean angular beam dispersion (X' , Y'), the rms beam size (X , Y) as well as the beam emittance (ϵ_x , ϵ_y), a classical beam diagnostic based on the detection of the electron induced Cerenkov radiation has been used for the present purpose.

As a first step prior to a more refined analysis, we present in the figure 2 the beam patterns and the related transverse profiles measured for a typical AIRIX cathode at a given location : longitudinal position $z=2.09$ m away from the cathode.

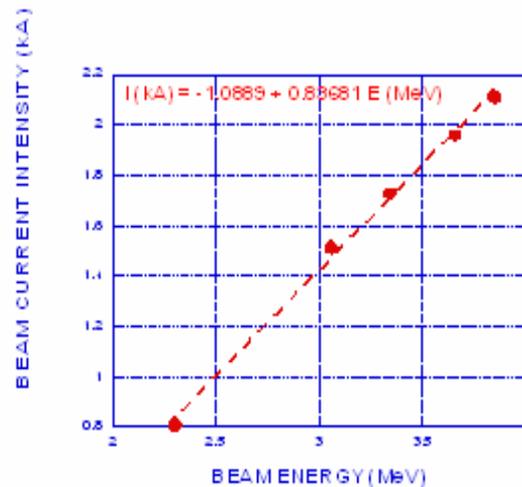


Figure 1: Beam current as a function of beam energy.

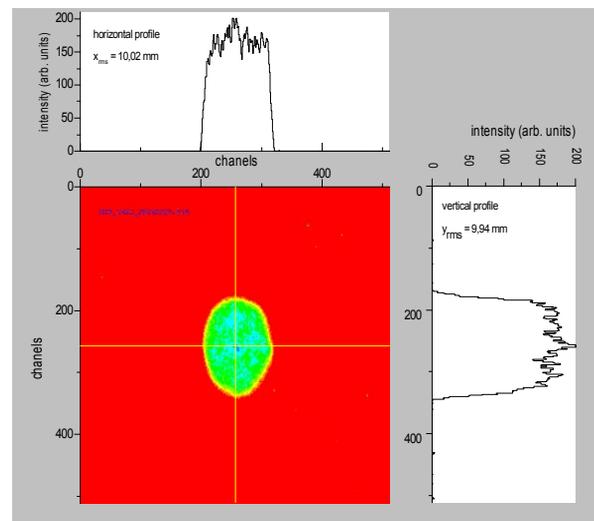


Figure 2: Beam profile.

In a more refined analysis, we vary the current of the solenoidal magnet placed a few meters upstream the beam diagnostic. This magnet is the extraction solenoid located

at $z=0.28$ m. The current of the solenoid varies from 180 A to 240 A. The measurement of the Cerenkov beam transverse dimensions X^* and Y^* (radii) is presented on the figure 3 with the radial error bars. For each value of the current, X^* and Y^* measurements are quite similar.

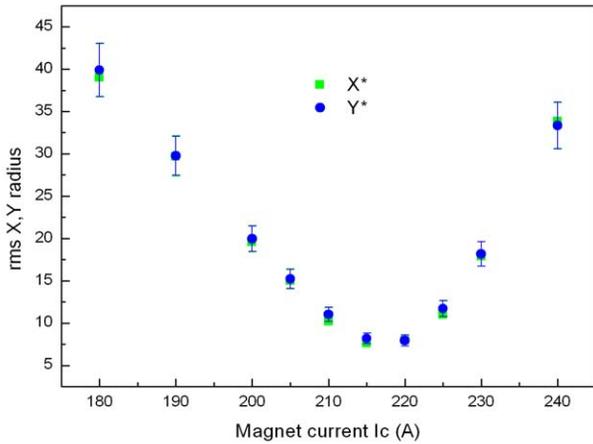


Figure 3: Beam radius Cerenkov measurement for different values of the solenoid current intensity.

We have seen that the beam sizes X_{rms} and Y_{rms} are measured downstream the diode output. The diode output corresponds to the initial conditions. Therefore, in order to get the relevant beam parameters ($X_{rms}^{(0)}$, $Y_{rms}^{(0)}$, $X'^{(0)}$, $Y'^{(0)}$ and $\epsilon_x^{(0)}$, $\epsilon_y^{(0)}$) at this location, numerical data treatments are required.

CALCULATED PARAMETERS

Minimization Method

At the beam diagnostic, located at $z=2.09$ m, the beam radii X^* and Y^* are measured with the errors ΔX and ΔY . The aim is to find the initial transport conditions (X, X', ϵ_x) and (Y, Y', ϵ_y) minimizing the χ^2 function, given by the following expression :

$$\chi^2 = \sum_{i=1}^n \frac{(X_i - X_i^*)^2}{\Delta X_i^2} + \frac{(Y_i - Y_i^*)^2}{\Delta Y_i^2}$$

In this expression, X^* and Y^* are the Cerenkov measured radii with the standard deviations (errors) ΔX and ΔY . The X and Y variables are the calculated radii on the diagnostic. The index i refers to each measurement.

Calculation of Initial Conditions

As a first step we obtain an estimation of the the initial conditions with the 1D code ENV coupled with the CONDINIT program [8] which uses a three gradient technique. The code calculates the following results :

$X = 19.3$ mm, $X' = 64.6$ mrad, $\epsilon_x = 250$ mm.mrad.

For the MINUIT library, we will give a domain around those approximate results. To obtain the initial conditions

(X, X', ϵ_x), in the transverse direction (x), we search a value respectively in the interval $[15;25]$ (mm), $[60;70]$ (mrad), and $[220;270]$ (mm.mrad). For the (y) direction we consider the same domains for (Y, Y', ϵ_y).

The figure 4 shows the final listing output of the MINUIT and TRAJENV computer diagnostics. The calculated initial beam conditions are written under the title "CONDITIONS INITIALES". The calculated values of dimensions X and Y at the Cerenkov beam diagnostic are listed under the title "CALCULS AU DIAG. OPTIQUE".

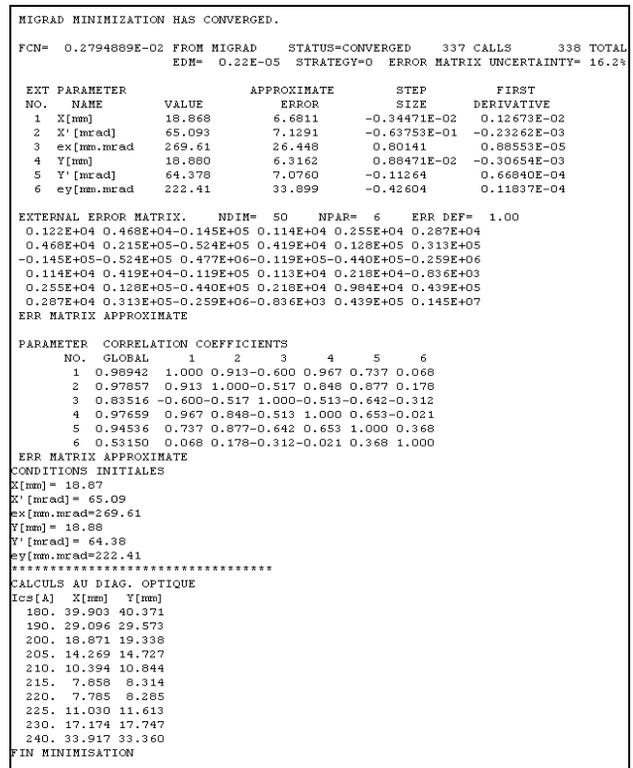


Figure 4: Listing output of calculated initial beam conditions and beam dimensions on the diagnostic.

The figure 5 shows a graphic presentation of the beam envelope given by the TRAJENV code with the calculated initial beam parameters along the trajectory between the extraction solenoid (first rectangular icon on the left) and the first induction cells (other rectangular icons).



Figure 5: Beam envelope given by the TRAJENV code.

The figure 6 shows the radius as a function of the solenoidal current. The simulation is in very good agreement with experiment in both directions (x) and (y). For both transverse directions, the TRAJENV code coupled with MINUIT gives the following initial conditions :

$X = 19.0$ mm, $X' = 66.0$ mrad, $\epsilon_x = 268$ mm.mrad ;
 $Y = 19.1$ mm, $Y' = 65.3$ mrad, $\epsilon_y = 221$ mm.mrad.

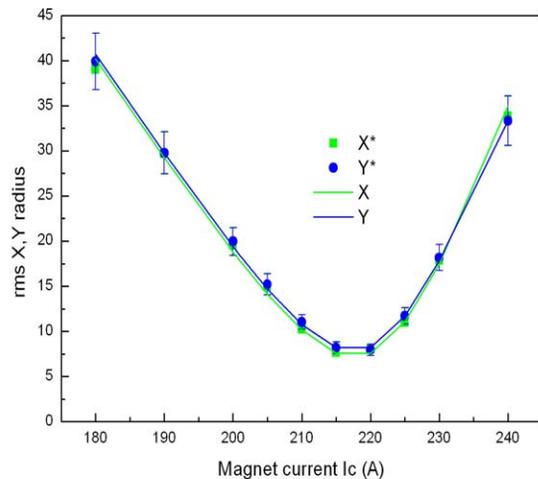


Figure 6: Beam simulated radii compared to experimental results for different values of the solenoid current.

CONCLUSION

We described a method to determine the unknown initial beam parameters (X, X'), (Y, Y') and (ϵ_x, ϵ_y) from beam dimensions measurements on a downstream Cerenkov diagnostic. We use the TRAJENV code coupled to a χ^2 minimization process from the CERN MINUIT library. Further developments are foresighted using these technique to reduce the number of machine shots dedicated to beam alignment.

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