COMPUTER ASSISTED ELECTRON BEAM CENTROID CHARACTERIZATION AT AIRIX FACILITY

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Abstract

AIRIX is a high current linac accelerator designed for flash X-ray radiography. The electron beam produced into a vacuum diode (2 kA, 3.5 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 cannot be measured. We have shown how to calculate the initial envelope parameters with the TRAJENV code [1]. Now we determine the centroid ones. Note that TRAJENV simulates beam transport [2-3] with a matrix method [4]. The code is coupled with the MINUIT minimization library [5-6] 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.

BEAM CENTERING STRATEGIES

Beam centring is controlled by means of a set of beam positioning monitors (BPM) located all along the accelerator line. It is performed by means of steerers that consist of correction coils (2 for vertical beam motion as well as 2 for horizontal one). Some successively trials are required for testing relative displacement of the beam as a function of the current intensity coil. For instance, three trials are needed to ensure that the beam will be located at the right position at a BPM. In addition, seven trials are required to make sure that the beam follows the right trajectory between two BPMs. Then, coil current intensities are adjusted in such a way that the beam position sticks to the BPM centres and that the beam trajectory remains as far as possible colinear with accelerator axis. To complete the accelerator tuning, we repeat the centring procedure of the beam along the accelerator to maintain the beam centroid to less than 1 mm from the axis of accelerator.

An another strategy consists in using a computer minimization method to determine the centroid positions by comparison with the experimental measurements. In this case, we can use only one trial for all BPMs positions.

THE CENTROID PARAMETERS

For a complete beam characterization, 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 initial beam envelope parameters (radii $X_{rms}^{(0)}$, $Y_{rms}^{(0)}$, divergences $X'^{(0)}$, $Y'^{(0)}$ and emittance $\varepsilon_x^{(0)}$, $\varepsilon_y^{(0)}$) as well as the beam centroid transverse position (x_c,y_c) and divergence (x_c',y_c').

EXPERIMENTAL PARAMETERS

We have seen how primary beam current intensity and beam energy are determined experimentally and how to calculate the beam envelope parameters [1].

In order to calculate the initial beam centroid transverse position and divergence, we measure these parameters with BPMs located in the initial drift space upstream the induction accelerator cells. Their location are 0.26 m, 0.81 m, 2.1 m and 2.4 m.

The beam centroid transverse position measurements x_c* and y_c* are presented on the figure 1 with the radii error bars, too small to be visible (30 µm for x_c and y_c). Measurements at two successive BPMs can be slightly different because of a quick variation of the beam centroid trajectory.

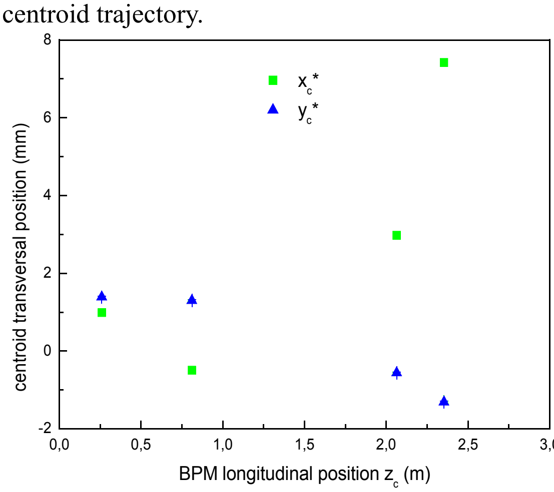

Figure 1 : Beam position measurement at the BPMs in the initial drift space.

We have seen that the centroid position (x_c,y_c) is measured downstream the diode output. The initial conditions corresponds to the diode output. Therefore, in order to get the relevant beam initial parameters $(x_c^{(0)}, y_c^{(0)})$ at this location, numerical data treatments are required.

CALCULATED PARAMETERS

Minimization method

We calculate first with TRAJENV the beam envelope parameters as given by the method already presented in reference [1]. Since the centroid transverse displacement is small enough, $(x_c,y_c) << (X_{rms},Y_{rms})$, the beam radius remains unchanged. Therefore, we can use this method independently of the steering magnetic field. From this step, we can apply the following method to calculate the initial centroid conditions.

At the BPMs, the beam radii x_c* and y_c* are measured with the errors Δx_c and Δy_c. The aim is to find the initial transport conditions (x_c,x_c') and (y_c,y_c') minimizing the χ^2 function, given by the following expression :

$$\chi^2 = \sum_{i=1}^{n} \frac{(x_{c,i} - x_{c,i}^*)^2}{\Delta x_{c,i}^2} + \frac{(y_{c,i} - y_{c,i}^*)^2}{\Delta y_{c,i}^2}$$

In this expression, $x_{c,i}$* and $y_{c,i}$* are the measured positions with the standard deviations (errors) Δx_c and Δy_c. The x_c and y_c variables are the calculated radii at the diagnostic position. The index i refers to each BPM.

To initialize the MINUIT library, we have to define a calculation domain that must include the solution.

Validation of the method

To validate the method, we calculate the beam transport with TRAJENV using arbitrary initial conditions, $(x_c,y_c)=(0.2,0)$ mm and $(x_c',y_c')=(0,0)$ mrad. From the centroid positions at BPMs locations, we consider the calculated values as pseudo-measurements. Then, in the domain [-30;30] (mm) and [-10;10] (mrad), running TRAJENV with MINUIT, we search the initial condition. If the method is valid, this solution should be the same as the arbitrary one.

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 the positions x_c and y_c at the BPMs diagnostics are listed under the title "MESURES ET CALCULS".The minimization gives the initial conditions again. Therefore it validates the method.

```
 MIGRAD MINIMIZATION HAS CONVERGED.

 FCN=  0.1185213E-07 FROM MIGRAD    STATUS=CONVERGED     33 CALLS       34
                     EDM=  0.75E-10    STRATEGY= 0      NO ERROR MATRIX

  EXT PARAMETER                 CURRENT GUESS       STEP         FIRST
  NO.   NAME        VALUE          ERROR            SIZE       DERIVATIVE
   1   xc[mm]      0.20068        1.5000        0.59265E-02  -0.11863E-04
   2   xc'[mrad]  -0.18566E-02    1.5000        0.22221E-01   0.32763E-05
   3   yc[mm]     -0.28606E-03    1.5000        0.36560E-04   0.25854E-06
   4   yc'[mrad]   0.54599E-02    1.5000        0.12979E-03  -0.68014E-07
 NO ERROR MATRIX
********************
CONDITIONS INITIALES
xc[mm]=  0.20
xc'[mrad]=  0.00
yc[mm]=  0.00
yc'[mrad]=  0.01
MESURES ET CALCULS
dpf xc*[mm]     xc[mm]        %          yc*[mm]     yc[mm]        %
  1 0.19        0.19        0.62        0.01        0.01        12.07
  2 -0.37       -0.37       0.46        -0.24       -0.24       0.08
  3 -4.38       -4.38       0.09        -0.96       -0.96       0.12
  4 -5.96       -5.96       0.05        -1.17       -1.17       0.06
FIN MINIMISATION
```

Figure 2 : Listing output of initial centroid conditions, calculated and pseudo-measured centroid positions on BPMs (dpf).

Comparison with experiment

We consider the previous calculation domain and measurements at BPMs. The figures 3 show the centroid trajectory in the drift space as showed by TRAJENV with the estimate conditions (dashed lines) and with the solution obtained after minimization (plain lines). The figure 4 shows the final listing output.

The centroid radius as a function of longitudinal position is showed on the figure 5. The simulation is not consistent with experimental results. The difference between calculation and experiment could be caused by a steering field which is not taken into account in the drift space. A probable explanation might be the misalignment of the extraction solenoid located a few meters upstream the last BPM in the drift space. The solenoid might be lightly tilted or shifted. In order to confirm this assumption, we will proceed to an accurate measurement of solenoid magnetic field.

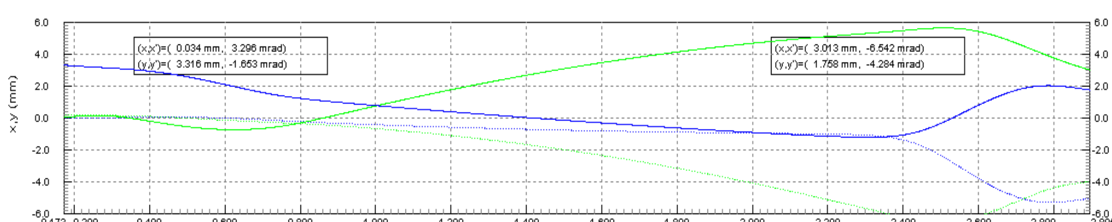

Figure 3. Centroid trajectory in the drift space obtained from the TRAJENV code.

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MIGRAD MINIMIZATION HAS CONVERGED.

FCN=  0.1172438E-02 FROM MIGRAD    STATUS=CONVERGED     62 CALLS       63
                    EDM=  0.95E-05  STRATEGY=0  ERROR MATRIX UNCERTAINTY=

 EXT PARAMETER                 APPROXIMATE        STEP          FIRST
 NO.   NAME         VALUE         ERROR           SIZE        DERIVATIVE
  1  xc[mm]       0.33570E-01    44.318       0.55285E-02   0.54244E-03
  2  xc'[mrad]     3.2963        36.144       0.26480E-01  -0.97792E-03
  3  yc[mm]        3.3163        44.713       0.22401E-02   0.17095E-02
  4  yc'[mrad]    -1.6530        33.528       0.19296E-01   0.96480E-03

EXTERNAL ERROR MATRIX.    NDIM=  50    NPAR=  4    ERR DEF=  1.00
 0.144E+04 0.369E+04 0.575E+03 0.243E+04
 0.369E+04 0.165E+05 0.228E+04 0.972E+04
 0.575E+03 0.228E+04 0.121E+04 0.273E+04
 0.243E+04 0.972E+04 0.273E+04 0.130E+05
ERR MATRIX APPROXIMATE

PARAMETER  CORRELATION COEFFICIENTS
      NO.  GLOBAL      1      2      3      4
       1  0.76029   1.000 0.756 0.436 0.560
       2  0.81029   0.756 1.000 0.511 0.663
       3  0.69132   0.436 0.511 1.000 0.687
       4  0.77866   0.560 0.663 0.687 1.000
ERR MATRIX APPROXIMATE
********************
CONDITIONS INITIALES
xc[mm]=  0.03
xc'[mrad]=  3.30
yc[mm]=  3.32
yc'[mrad]= -1.65
MESURES ET CALCULS
dpf xc*[mm]      xc[mm]         %          yc*[mm]       yc[mm]          %
  1 0.99         0.16         83.67        1.39          3.18          129.11
  2 -0.49        -0.24        50.49        1.30          1.20          7.87
  3 2.98         4.84         62.31        -0.56         -0.98         75.43
  4 7.42         5.40         27.29        -1.31         -1.17         10.36
FIN MINIMISATION
```

Figure 4 : Listing output of initial centroid conditions, calculated and measured centroid positions on BPMs (dpf).

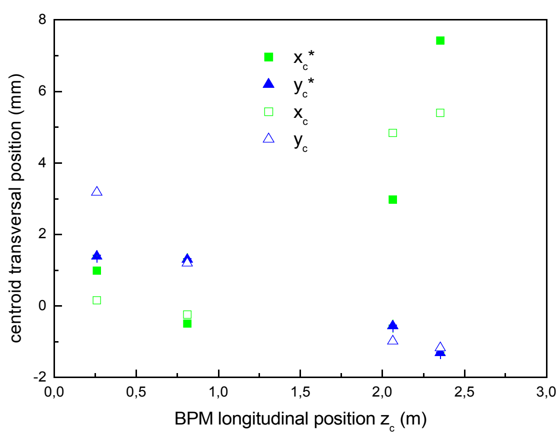

Figure 5: Beam calculated centroid position (calculated: empty symbols; experiment filled symbols).

CONCLUSION

We have described a method to determine the unknown initial beam parameters (x_c,x_c') and (y_c,y_c') from BPMs diagnostics. We use the TRAJENV code coupled to a χ^2 minimization process from the CERN MINUIT library. Disagreements were found compared to experimental results. We think they are corresponding to a misalignment of the extraction solenoid. Precise measurements of the magnetic field would confirm this assumption. In this case we should validate the method with experiment.

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