Transport optimization and characterization of the 2kA AIRIX electron beam

E. Merle, J. Delvaux, M. Mouillet, O. Pierret, J.C. Ribes
CEA / PEM 51490 PONTFAVERGER-MORONVILLIERS - FRANCE

J. Bardy, A. Devin
CEA / CESTA BP n°2 33114 LE BARP - FRANCE

Abstract

The AIRIX induction accelerator is now operational. After completing the acceptance test of the entire machine, we have aligned the sixteen blocks of four cells, each using the very accurate HLS (Hydrostatic Leveling System) and WPS (Wire Positionning System) method. The beam transport optimization was made with a 1.92kA,60ns electron beam, accelerated from 3.8 to 19.2MeV. This procedure consisted of minimizing the beam envelope and beam break up (BBU) oscillations. Two specific campaigns using OTR measurements with a fast gated camera, validated the beam transport calculations,. The good agreement between the experimental results and theorical predictions are presented. We will also present the effects of the beam centering procedure. The last section adresses the work that will be done on the machine, to operate at higher current (up to 3.5 kA), to decrease BBU oscillations and to reduce the X-ray focal spot size.

1 - INTRODUCTION

The installation of the AIRIX accelerator was completed in July 99 [1]. This accelerator is dedicated to flash X-ray radiography. One of the goals of the AIRIX project was to obtain an X-ray focal spot size of less than 2mm.

Although the acceptance test of the accelerator was made with a beam current of 3kA current, we have chosen a beam current of 1.92kA to optimize the beam transport and minimize the focal spot size. At this current, all the objectives of the project have been reached.

To minimize the chromatic effects (corkscrew motion), very severe technological constraints on the alignment of the solenoïd all along the machine have been imposed. We present, in a first section, the results of this very precise alignment system based on WPS (Wire Positionning System) and HLS systems (Hydrostatic Leveling System).

In a second section, we expose the beam initial parameters determination.

The third section deals with the beam transport optimization that consists of minimizing both the beam envelope oscillations and the Beam Break Up (BBU) oscillations. We present the two specific campaigns where we highlight the good agreement between calculations and beam diameter experimental measurements.

2 -ALIGNMENT OF THE ACCELERATOR

The alignment goals consisted of enclosing all the induction cell magnetic axes within a 250 µm diameter cylinder with an angle spread of less than 500 µrad around the reference beam axis. The procedure for alignment is as follows:

a- the induction cells are assembled in four cells blocks on a specific alignment bench. The mechanical references of the block are measured with respect to two standard references of the bench. For that, each block is equiped with two WPS and two HLS sensors [2].

b- the tilt and the offset of each magnetic axes are measured with respect to the mechanical références [3].

c- the block of 4 cells is installed on the machine, and the first alignment is made with a theodolite.

d- the two standard references of the bench are reproduced on the accelerator.

e- each block is then aligned on the accelerator, with respect to the two standard references of the accelerator, by reproducing the bench mechanical characteristics of the block.

Table 1 summarizes the results of step b, for all the 64 cells.

	Mean value	RMS	max.
Offsetx,y (µm)	30	45	90
tiltx,y(µrad)	700	400	1600

Table 1: tilt and offset result of the 64 cells.

Figure 1a shows the result of the alignment of the 16 cells blocks, prior to using HLS and WPS (step c). This is compared to the final alignment (step e) in figure 1b. We can see that the HLS and WPS method produce an improvement of a factor of 10 in the accuracy of the alignment. This is necessary to meet the alignment requirements stated above and demonstates that simple theodolite alignment is not sufficient. This method also permits the alignment of each cell block without breaking the beamline vacuum.

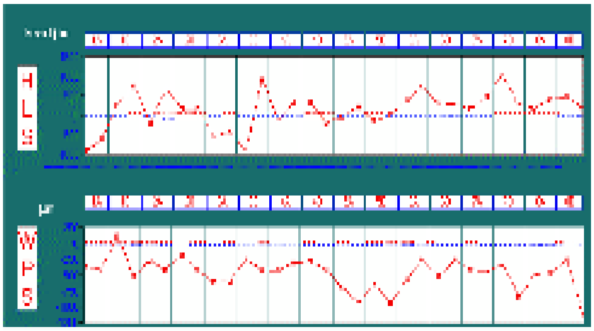

figure 1a: alignment status after theodolite alignment

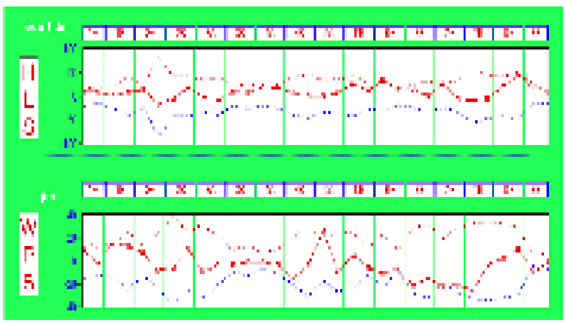

figure 1b: alignment status after HLS-WPS alignment

The dashed lines, represent the maximum acceptable misaligment for each block, to respect the initial constraints.

2 - BEAM INITIAL PARAMETERS

To operate with a 2kA electron beam we use a 51mm diameter velvet cathode, with a velvet recess of 3.6mm. For the determination of the inital beam parameters we first established the relationship: E=f(I), where I is the beam current and E the nominal diode energy, measured with a time resolved spectrometer [4]. We obtained 1.92kA electron beam for 3.8MeV energy:

$$E\ (\text{MeV}) = 1.436\ I_{bpm2}\ (\text{kA}) + 1.083$$

The evaluation of the three parameters Ro, R'o (radius and slope of the beam envelop at the origin), and ε (emittance) was made with the classical three gradients method (Table 2, figure 2).

Axis	Ro (mm)	R'o (mm)	ε (π mm mrad)	f.o.m.
X	19.9	69.6	248	2.12

Table 2: beam initial parameter for 1.92kA/3.8MeV

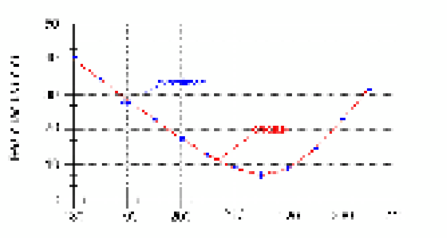

Figure 2: Beam radius versus extraction coil current

The emittance value is particularly small compared to the 800 π mm mrad that we expected. Nevertheless, the agreement between the calculated values of the beam diameter and the measured ones, is quiet good because the factor of merit (f.o.m.) is low. We will see in the following sections that the transport calculations are better with this emittance value.

3 - BEAM TRANSPORT OPTIMIZATION

The electron beam transport is calculated with the ENV code [5], based on the classical envelope equation [6]. The first constraints affecting the beam transport are the drift spaces present on the machine: the longest is located between the injector and the accelerator (≈ 2m), and the 9 others (≈ 0.8m), are located at the pumping modules. This configuration limits the possibilities for the guiding magnet current. We look for the magnetic field parameters that minimize envelope oscillations along the accelerator.

The BBU oscillations can be minimized with the higher magnetic fields [7]. On the other hand, chromatic effects (corkscrew motion) are minimized if the magnetic field is low. The optimum balance is to have a magnetic field growth proportionally to the square root of the beam energy ($\sqrt{\gamma}$).

Thus, the optimum for the guiding coil current, is a compromise between those three essential constraints. We have worked essentially with the magnetic transport field presented on figure 3.

The drift section after the accelerator includes three guiding coils and a final one that is very close to the target, to focus the beam to as small a diameter as possible. Before determining the current on the first three coils, we have improved the beam transport code to obtain the correct beam parameters after transport and acceleration along the machine. We monitor beam size, 1m after the third coil at a beam stop (BS on figure 3) that contains an OTR foil. The axial magnetic variation was made on the second coil (B2 on figure 3). The OTR (Optical Transition Radiation) observation was made with a fast gated camera (25 ns gate) and the results are showed on the figure 4.

The different calculations plotted model the electron beam throughout the entire accelertor and take into account the initial parameters exposed mentioned above.

This result shows the good prediction of the beam transport calculation all along the accelerator. We have arbitrarily changed the emittance value and did the calculation with 500 and 750 π mm mrad. The Figure 4 illustrates that the emittance is quiet low. Furthermore, if we calculate the beam parameters (R1, R'1, ε) before the B2 coil by using the above experimental data, we fine an emittance value near 300 π mm mrad, with a factor of merit of 2.5%.

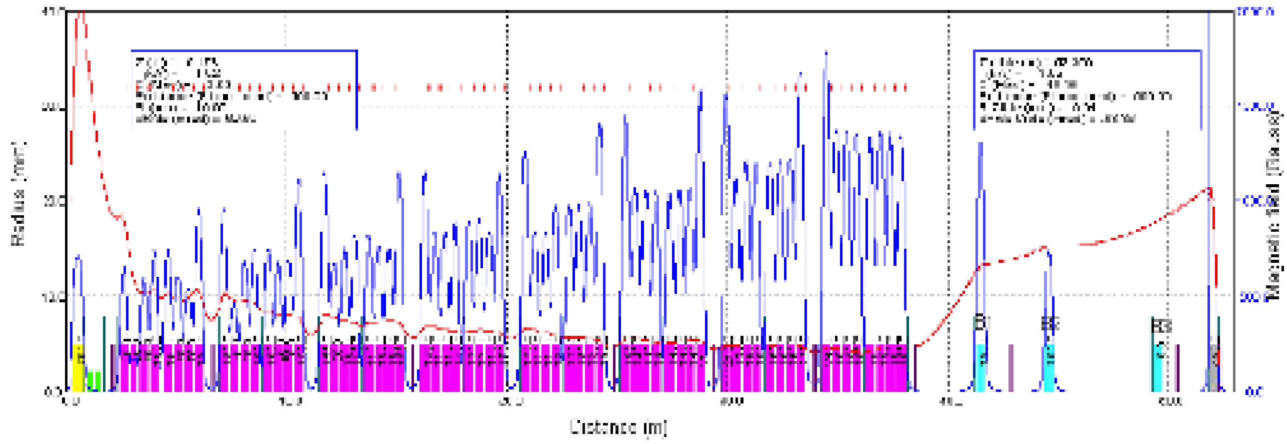

figure 3: beam envelop visualisation along the AIRIX accelerator

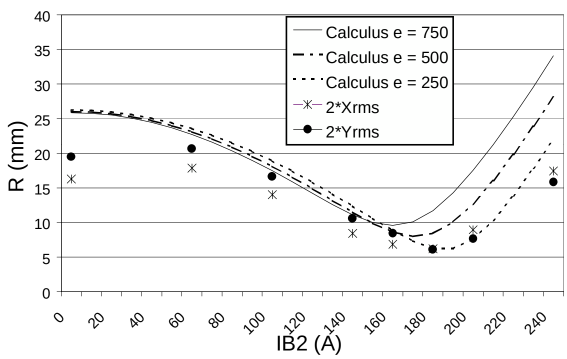

figure 4: beam imaging on the final beam stop (BS), with the B2 coil variation.

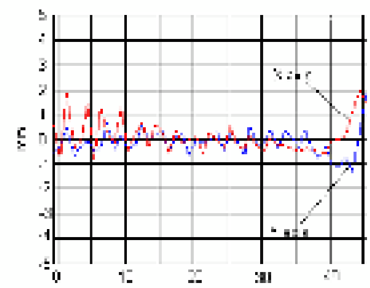

figure 5: transverse motion of the beam centroïde 5m after the 64^{th} cell.

Optimum transport of the electron beam requires centering the beam along the accelerator axis to minimize BBU oscillations. Therefore, the first step is to have the electron beam enter the accelerator with a zero angle, with respect to the reference axis. A procedure [1] conjugated with the accurate alignment tends to minimize BBU oscillations. The AIRIX induction cells have the ferrite in vacuum [8]. The main frequency for the transverse impedance of the accelerator is near 360 Mhz. At this frequency, the transverse beam motion is amplified along the accelerator. 2m after the exit of the last cell, where the beam has a diameter of approximately 30 mm, the amplitude for the BBU oscillations is ±0.5mm, wich is acceptable. At 5cm before the target, the last BPM (Beam Position Monitor), measures an amplitude of about ±0.2mm.

To reduce this amplitude, we plan to install a new coil between the injector and the accelerator. This will preserve the rise time of the beam and delay the creation of the BBU.

CONCLUSION

The initial performance of the AIRIX accelerator is very promising. The X-ray focal spot was measured to be less than 2mm in diameter [9]. All of the goals of the project have been reached with this 1.92kA, 19.2 MeV electron beam. Studies for electron beam dynamics, and diagnostics are continuing, to ameliorate the performances of each part of the machine.

REFERENCES

[1] M. Mouillet et al., Proc. of LINAC 2000.
[2] J.Bardy et al., 'Status of ARIX alignment and high current electron beam diagnostics' - Proc. of EPAC 96
[3] C. Bonnafond et al., ' ' - Proc. of PAC 99.
[4] D. Villate et al., 'AIRIX alignment and high current electron beam diagnostics', Proc. of PAC 95
[5] J.Bardy - ENV 'Envelop electron beam transport code', Private communication.
[6] E. Merle et al., 'Status of the AIRIX accelerator', Proc. of PAC 99.
[7] S. Humphries 'Charged particle beams', Wiley Interscience publication
[8] E. Merle et al. 'High current and high energy AIRIX induction accelerator development', Proc. of EPAC 96.
[9] C. Cavailler, 'AIRIX, a new tool for flash radiography in detonics' Proc. of ICHSPP24, 24-29 sept. 2000