DIAGNOSTICS DEVELOPMENT FOR HIGH CURRENT ELECTRON ACCELERATORS AT CESTA

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Abstract

Some applications of the Induction Accelerators require high quality electron beams and among them we are mainly interested in Free Electron Laser (FEL) experiments and the achievement of the AIRIX high performance Radiographic Hydrotest Facility. In both cases small emittance and energy spread are needed to fulfill the experimental requirements. Beam diagnostics have been developed in order to allow a better knowledge of the main parameters and hence to optimize it. Since pulsed Accelerators, and namely Induction Linacs, have essentially time dependant characteristics, it is necessary for most of the diagnostics to be time resolved. We describe the emittance measurement which uses the Cerenkov radiation from a thin window on a gated camera to record and process the image of a pepper-pot. A new electron magnetic spectrometer is presented which includes high energy resolution optical fibers and streak camera recording. Other diagnostics are discussed such as beam position measurements.

I - INTRODUCTION

In high current electron accelerators, such as Induction Linacs, mechanical and magnetic aligment is a key topic for the beam transport and the emittance conservation along the accelerator. Small amplitude misalignments can be the cause of aberrations and instabilities that prevent the beam from being properly transported and focused. For high current (kA), low energy (few MeV) pulsed devices, only beam position monitors (BPM) using B-loops can be used as non-destructive diagnostics. Other diagnostics that stop the beam are needed to measure the beam emittance, the beam contour and position, the energy spectrum of electrons. They often use optical observation of the Cerenkov radiation from a thin target placed on the beam path. At higher energies, over 10 MeV, it may be helpful to consider the Optical Transition Radiation (OTR) as a powerful and non-destructive beam diagnostic.

Some experimental devices and first results are presented. The beam facilities devoted to these developments are the LELIA Induction Accelerator, the EUPHROSYNE pulsed electron generator, and the ALEXIS RF accelerator (for OTR studies).

II ALIGNMENT

The alignment of charged particles accelerators has two components : mechanical alignment and magnetic alignment.

A - Mechanical alignment

On the LELIA accelerator we have used a device with a He-Ne laser and position detectors located on the mechanical axis of each part of the accelerator. It allows to measure gaps between an ideal straight line and the actual axes of the cells with an accuracy of 50 µm over a 30 m machine.

B - Magnetic alignment

The magnetic coils allowing the beam to be guided into the accelerator are mechanically bound to the cells. Magnetic axis of each coil is checked in translation and rotation by the use of the stretched wire technique. It allows to point out offsets of 50 µm and tilts of 10 µrad. Only tilts in rotation can be eliminated by the help of steering coils.

C - AIRIX Alignment

We are currently studying procedures for assembling the cells and achieving the whole accelerator alignment.

The problem of marking the difference between mechanical and magnetic axis should be solved by the assembling technique of the different parts of the accelerator and the use of homogenizer rings [1] mechanically centered in the coils. References, carrying back the magnetic axis to the outside of the structures, will make possible a dynamic realignment of the accelerator.

III - EMITTANCE MEASUREMENTS

This diagnostic has been performed to measure time resolved electron beam transverse emittance by using the pepper-pot technique. Characteristics of the beams are typically 1 to 3 kA and 1 to 6 MeV for a pulse duration around 50 nsec. The beam entering the pepper-pot is screened by a plate which holds a set of holes regularly spaced in the two transverse directions of the beam. The emerging beamlets, after travelling a drift length L, strike the analysis plane (silica window) for electron-photon Cerenkov conversion. But here care has to be taken of the spatial resolution connected with the thickness of the interaction target. The transverse emittance is then defined as the trace space area divided by π occupied by the beam in one direction. This area is determined by analyzing the beamlet distribution. Thus, emittance can be measured in the two transverse directions simultaneously.

The mechanical parameters of the diagnostic have been calculated with the help of an envelope code. For the design of the AIRIX emittancemeter at E = 4 MeV, I = 3 kA and $\varepsilon = 100\pi$ mm mrad we obtained the values indicated on the figure 1. This experimental set up consists in :

- a vacuum tank with the selection and analysis planes
- a CCD camera (with gating from 3 nsec to 300 msec) located 90° from the beam axis to record the beamlet distributions. This camera is packed in a lead box inside a Faraday cage to shield it from X rays and electromagnetic radiations,
- a computer in order to analyze the pepper-pot image and calculate the emittance value. An image processing has been performed.

This apparatus is currently being tested with the EUPHROSYNE generator before being put on the LELIA beam. It will then be used for the measurement of the emittance of the AIRIX injector electron beam.

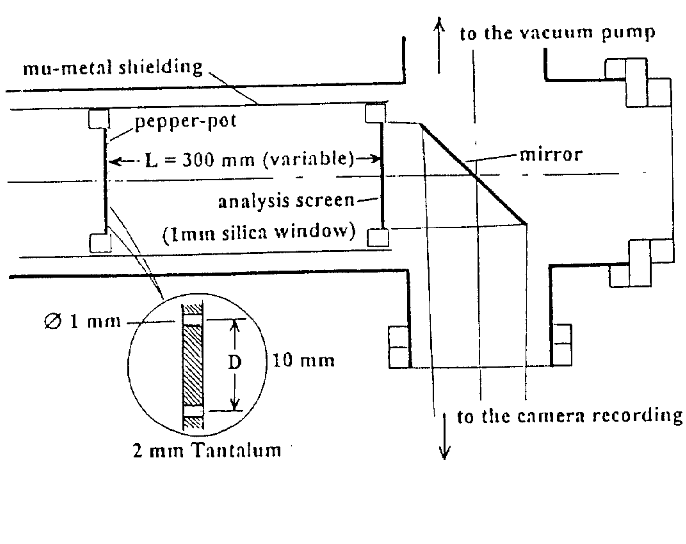

Figure 1 : AIRIX emittance layout

IV - SPECTROMETER

A magnetic spectrometer is being tested which allows to analyze the electron energy versus time between 1 and 10 MeV.

Its principle is founded on a 180° magnetic deviation obtained with the help of an electromagnet. The magnetic field is measured by a Nuclear Magnetic Resonance probe giving an absolute accuracy around 10^{-5}.

The analyzing plane can be equipped with different detectors such as a film (no more time resolved measurements in this case), a set of 28 Faraday cups allowing, over an energy range of 0.5E, resolutions of Δ E/E = 2 % and Δt = 3nsec, and two sheets of 100 optical fibers. (see Figure 2)

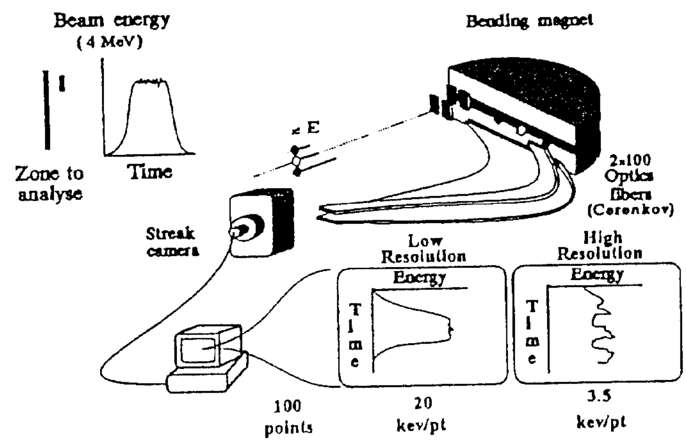

Figure 2 : Spectrometer

In this last case, the Cerenkov radiation emitted by electrons into the fibers is guided to a streak Camera which allows a continuous time analysis with a 1 nsec resolution. For the first sheet of fibers the resolution is ΔE/E = 0,5 %, over an energy range of 0,5E. The second sheet with fibers placed side by side provides a resolution ΔE/E = 0,1 % over a 0,1 E energy range.

The electron path has been numerically simulated by following the particles in the actual field given by a magnetic cartography of the air gap.

Calibration of the whole is achieved at low energy ($\approx$ 0,6 MeV) thanks to a Cs-Ba β source and a counting system.

V - BEAM POSITION

A - B_θ loops

Determination of the electron beam position is obtained from measurements given by 4 loops influenced by the B_θ field generated by the beam.

A beam calibration, using a wire (which simulates the beam) gives the result when centring is perfect and then when a few millimeters off-axis displacement is imposed.

The voltage pulse delivered by each loop is proportional to the time derivative of current.The intégration is mathematically obtained. This can be the cause of errors due to the evaluation of the continuous level of offset. It would probably be better to process the signal after being integrated in a high bandwith (2 GHz) integrator allowing to observe fast fluctuations of the beam centroid. An other way of improving the diagnostic could be the use of calibrated beam instead of a wire.

B - Optical measurements

Spatial profile and position of the beam in the pipe are analyzed. Electron-photon converters allowing to obtain an " image " of the beam are inserted in the guiding channel. They often use Cerenkov radiation from a thin target. Such measurements have been achieved on the LELIA injector at 1.3 MeV using a fast gated camera giving a 5 nsec time resolution. As an alternative, the use of a streak camera can provide a continuous analysis of a transverse diameter of the beam with a time resolution around 1 nsec.

VI - OPTICAL TRANSITION RADIATION

It occurs when a charged particle crosses the interface separating two mediums having different dielectric indices[2-4]. As a first advantage this radiation is emitted as well forward than backward in visible lobes distinctly orientated. It can provide measurements of beam position and profile, but in addition it can give access to the beam energy since the angular separation of the lobes presents a $1/\gamma$ variation.An other advantage is the result of the nature of this radiation, depending only on the index variation. It allows a thin membrane to be used as target with only few perturbation in the beam transport.

We have an RF accelerator with a 13 to 20 MeV energy and a 400 mA intensity in macropulses of 5 µsec duration (ALEXIS). An experiment has been installed to study OTR in this energy range and first results are interesting. We anticipate a useful application of these techniques to the high energy part of the future AIRIX Accelerator.

VII - OUTLOOK

These diagnostics appear directly connected with the development of the AIRIX program. In particular the new time-resolved energy spectrometer and the emittancemeter described above are intented for measurements of the beam characteristics of the AIRIX injector (4 MeV-3.5 kA - 60 nsec) now under construction . They are planed for the optimization of the beam in the PIVAIR milestone [5] before the completion of the AIRIX Accelerator.

VII - REFERENCES

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