Beam Diagnostics with OTR at the SC Linac LISA

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Abstract

First preliminary experimental results on the use as a diagnostic tool of Optical Transition Radiation emitted by a 1 MeV electron beam produced by the Superconducting Linac LISA are presented.

1 - Introduction

Transition Radiation, i.e. the radiation emitted by a charged particle when crossing the boundaring between two different media at constant velocity, was the last discovered radiation process in electromagnetic theory [1].

With a pioneer work, between 1972 and 1975 L. Wartski demonstrated the possibility of using the Transition Radiation in the optical range (OTR) as a diagnostic tool for relativistic electron beams [2,3]. In particolar he showed that the beam angular divergence could be measured both by the analysis of a single foil emission and, with much more sensitivity, by the interference between the emission of two foil, the OTR interferometer. The low intensity of OTR, toghether with the relatively small bunch charge delivered by the electron linacs at that time, prevented further development of ihis work.

Much later, Rule and Fiorito developed a complete series of diagnostic tools, based on OTR, taking advantage of the large charge per pulse produced by modern linacs designed for high power FEL, exploiting also the almost istantaneous emission of OTR for a time resolved analysis of beam parameters [4,5,6].

In Superconducting Linacs the long macropulse, up to few milliseconds, easily compensate for the rather low charge per micropulse, and the requirement of beam stability, which is one of the main characteristics of this kind of linacs, makes the OTR based diagnostics a very useful instrument.

This is the main reason for our considering to make extensive use of OTR in the beam diagnostics of the 25 MeV superconducting linac LISA, to measure energy stability and emittance.

During the commissioning of the 1 MeV injector, we also used OTR for the diagnostics of some beam parameters.

In this paper we illustrate the results so far obtained at low energy toghether with the measurements we are planning with the full energy beam.

1 - OTR at 1 MeV

A detailed analysis of OTR emitted by an 1 MeV beam, toghether with its diagnostics capability, is presented in [7]. In Fig. 1 we show the calculated angular pattern of the radiation.

The radiation backward emitted by a polished bulk aluminum screen was easily visible with a standard CCD camera even at an average current almost an order of magnitude lower than the nominal value of 2 mA, thanks to a 2.5 ms long macropulse. On the other hand, quantitative measurements were only possible when 1 mA was reached.

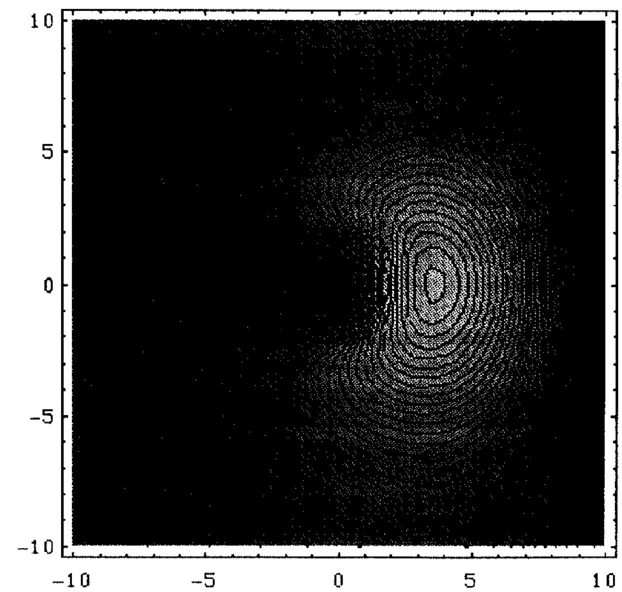


Fig. 1 - OTR radiation pattern backward emitted from an aluminum target by a 1 MeV electron. The borders of the figure correspond to a 45° emission with respect to the reflection axis

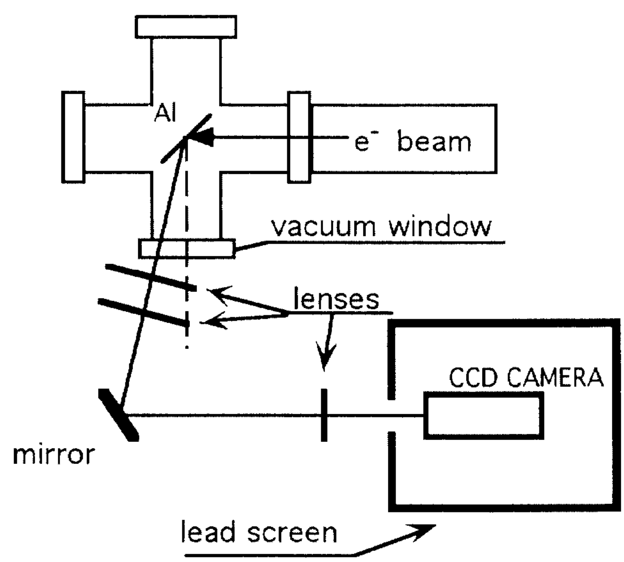


Fig. 2 - Schematic layout of the experimental set-up

At first, we attempted to observe OTR radiation aligning the optical system on the specular reflection axis. Since standard lenses of short focal length and large diameter were used, the strong spherical aberrations of the system together with the wide angle of OTR emission prevented a clear focusing of the source point. After this unsuccessful attempt, we decided to detect only the high intensity lobe emitted at .3 rad from the normal to the beam. The experimental layout is shown in Fig. 2.

In spite of the lead shielding of the camera, the images were rather noisy due to the very high x-ray intensity emitted by the beam when stopped by the bulk screen (the vacuum window was browned in a short time by this radiation). Averaging over few macropulses almost completely removed the noise allowing beam profile measurements.
Examples of beam image are shown in Fig. 4.

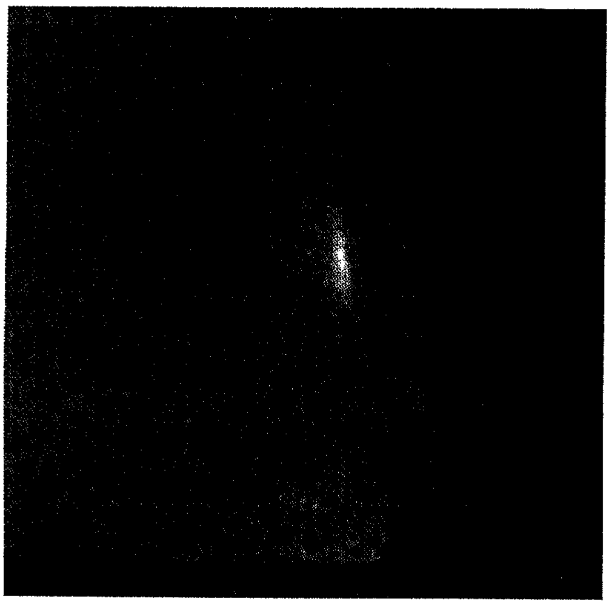


Fig. 3 - OTR beam image from a 1.5 mA, 2 ms electron beam filtered by an horizontal polarizer

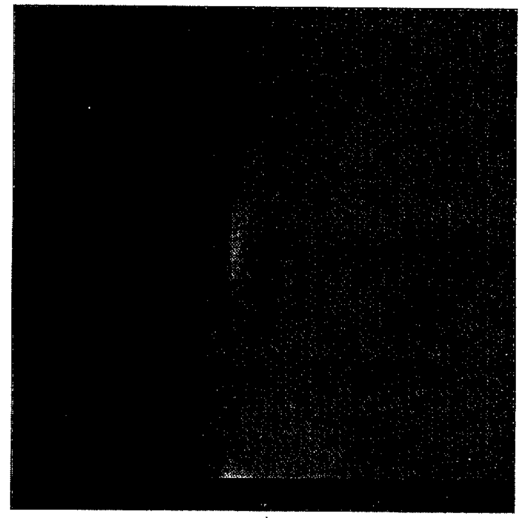
At the time of these measurements the transport efficiency of the 1 MeV beam was of the order of 80%, so that the diffuse backgroud seen in Fig. 3 is due to fluorescent radiation emitted by lost electrons hitting the aluminum vacuum chamber and reflected by the mirror.

The nature of detected radiation was confirmed by the insertion of two polarizers, selecting respectively horizontal and vertical polarization.

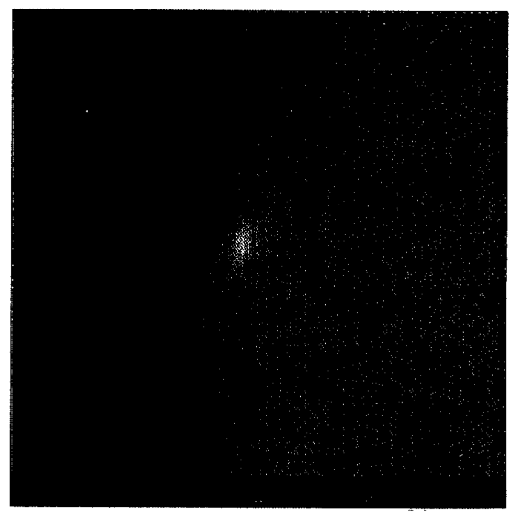
With the horizontal polarizer the radiation was only slightly reduced due to the non perfect transmissivity of the polarizer itself (see Fig. 3), while with the vertical one no signal was detected over the noise, as predicted by OTR theory.

With the described set-up, a transverse emittance measurement has been performed analysing the beam profiles variation as a function of the focal strength of an upstream quadrupole.

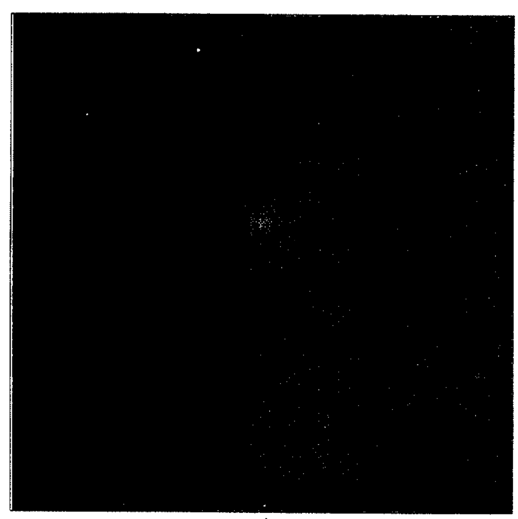
In Fig. 4 a), b), c) three images at different quadrupole setting are shown.



a)



b)



c)

Fig. 4 a), b), c) - Beam images at different quadrupole setting

A tipical example of beam profile is shown in Fig. 5, toghether with a fit of a gaussian distribution plus a linear increasing backgroud.

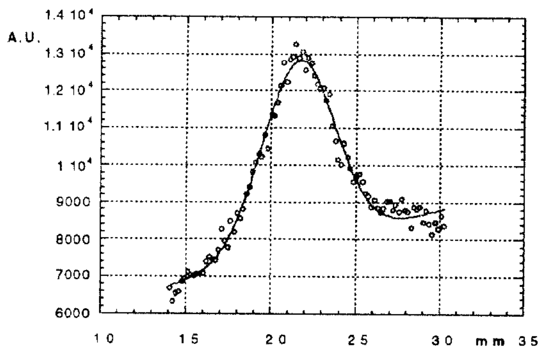


Fig. 5 - Typical exemple of beam profile. The continuos line is a fit of a gaussian distribution over a linear increasing background

Fig. 6 shows the behavior of the square of beam dimension as a function of the quadrupole current. A parabolic fit to these data allows the reconstruction of the beam Twiss functions and of the emittance.

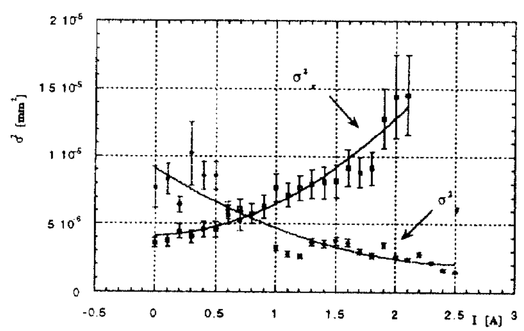


Fig. 6 - Square of the tranverse beam dimensions (σ) as a function of quadrupole current

The emittance values ($\sigma\sigma'$) result 1.7 10^{-7} in the vertical plane and 2.4 10^{-7} in the horizontal one.

3 - OTR at 25 MeV

A more conventional set-up will be used for OTR study at 25 MeV. The research program is more ambitious, aiming at developping systems for time resolved measurements along the macropulse. Two kinds of detectors, respectively based on a multianode PMT and a linear CCD device, are under construction.

Since the angular aperture of the lobes of the OTR emission is $\theta \sim 1/\gamma$ the radiation is confined in a narrow cone around the axis of specular reflection . A 1:1 or smaller imaging on the CCD of a TV camera without objective is obtainable with a single lens. Moreover, an objective with focal length f=75mm and 50 mm diameter, focusing at infinity, gives the angular distribution pattern on the image plane; the peak separation is $2\theta f \sim 3$mm, compatible with the physical size of the CCD.

In our set up two cameras are placed on a movable table, so that either the imaging or the angular distribution can be obtained translating the table.

Preliminary observation at ~ 15 MeV showed images much more noisy that those obtained at 1 MeV. The set-up for 1 MeV is placed soon after a bending magnet so that it collects light only from a short part of the upstream pipe. On the other hand, the 25 MeV set up is aligned with the SC linac and the 1 MeV straight transport line, therefore the mirror collects fluorescence light emitted all along the accelerator by electrons hitting the inner wall of the vacuum pipe.

Improving the performances of the SC cavities will certainly reduce the amount of electrons lost, mainly due to dark current which is badly controlled in the downstream transport line.

However, since the light due to fluorescence lasts much longer than the pulse length it will be largely rejected by fast detector operating only during the macropulse.

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