OPTICAL TRANSITION RADIATION MEASUREMENTS ON THE ELETTRA LINAC

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Abstract

An experimental apparatus has been developed and installed on the Elettra Linac in Trieste in order to measure OTR spectra at energies below 100 MeV.
In this paper we report the results so far obtained at electron energies between 30 and 100 MeV. Beam diagnostics obtained from OTR data will be discussed

INTRODUCTION

Beam monitors using electromagnetic waves, especially visible light radiated by charged particles, have several excellent and unique features for beam diagnostics: they are free from environmental electromagnetic noise and are characterized by high-speed response time. OTR based beam diagnostics are beginning to be used more and more at accelerator facilities around the world. They are one of the most promising monitors concerning position, size, emittance, energy and time structures of bunches of electron beams.
OTR was first predicted by Ginzburg and Frank[(1)] in 1946, but its practical usefulness as an e-beam diagnostic was not explored until 1975 by Wartski[(2)]. During the 1980s further developments were carried out working with beam energies of the order of 100 MeV or higher[(3)].
OTR is generated when a charged particle beam crosses the interface between two media of different dielectric constants. For beam diagnostics it is usually used the radiation emitted from a vacuum-metal boundary. In practice a thin metal foil is inserted into the beam line at an oblique angle to the beam direction of motion. OTR is emitted in both forward and backward emisphere.
The fundamental characteristics of the transition radiation emission shows both a rather complicated relation between many different parameters and the coexistence of different regimes. This latter feature is mainly related to the dependence of the emission from the energy of the charged particles. The boundary between the so called "low-energy" and "high-energy" regimes may be found at a value of γ around 20[(4)]. In the following we are going to discuss and analyze the properties of electron beams in the high energy regime.
OTR main features are the large emission spectrum, the absence of an energy threshold, the polarization of the emitted radiation and a high directivity which increases with energy. Measurements have shown that no intrinsic limits are present in OTR that is resolved limited only by diffraction and optical setup[(5)]. This gives a beam diagnostic tool to measure beam profiles with an improved spatial resolution. The surface nature of the OTR allows to use very thin targets which gives reduction in beam scattering and bremsstrahlung radiation. OTR screens may work inserted on the beam line during beam transport to give on line monitoring of beam parameters.
The OTR angular distribution pattern can be exploited to measure beam divergence and energy. The distance of the two peaks (Δ) in the spectra is proportional to $1/\gamma^{-}$ and they present a 10% of unsimmetry along the observation angle. The minimum in the emission distribution overlaps with the beam reflection direction, so that a foil at 45° to the beam emits at 90°, the standard port geometry for accelerator lines.

THE EXPERIMENTAL SET-UP

The OTR measurement facility installed at Elettra Linac has been conceived to quantitatively study the dependence of OTR properties from:

- beam energy (in the range 30-100 MeV)
- beam intensity and distribution
- beam divergence
- screen materials and thickness
- beam incidence angle.

The measurement station is located at the end of the Linac preinjector where the electron beam has energies ranging from 30 to 100 MeV. A spectrometer positioned just before the OTR station provides a reference measurement for beam energies.
The diagnostic box (shown in fig. 1) has been specially designed with the following characteristics :

- the box has been machined in a way such that its mechanical alignment with respect to the beam line structure will guarantee the geometric relations between the beam direction and the OTR screen
- the pneumatic actuator which holds the OTR screen can be remotely moved under vacuum according to two degrees of freedom. The first allows to put at the beam intersection point two different screen types (OTR or alumina screen) or a free position for non perturbed beam transport. The second possible movement is a rotation of the full actuator in order to change the incidence angle of the beam on the screen.
- the viewing angle of the OTR window (assuming to collect backward radiation) is 900 mrad and it has

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been maximized in order to collect as much light as possible and to avoid the cut of the tails in angular distribution spectra.

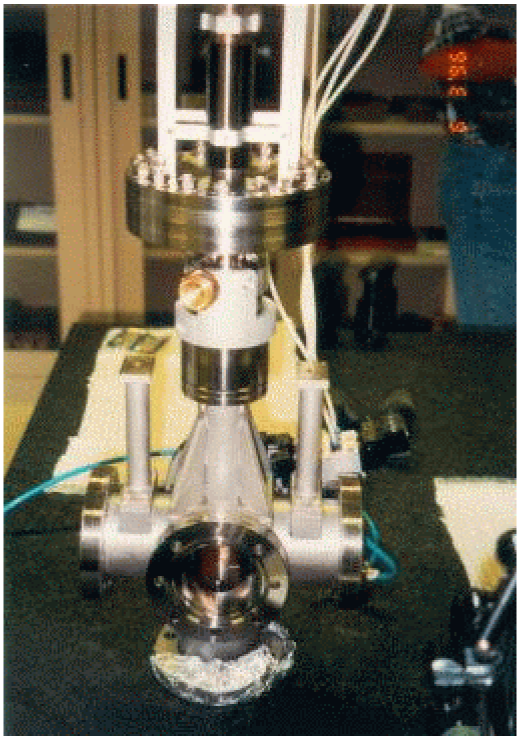

Fig. 1 OTR diagnostic box

The optical elements for light collection and transport from the radiator up to the detector have been assembled on an optical rail to guarantee the proper alignment characteristics (fig. 2). The rail has been positioned perpendicular to the beam direction within an accuracy of 0.1 mrad and each element has been assembled on the rail using linear translators (hand driven or remotely controlled) to adjust their final position.

The optical system was designed to have an angular field of view of about two times the peak angle of the OTR pattern at the lower energy used. The limiting aperture of the system is set by the detector size.

The system has been designed to allow simultaneous monitoring of the beam image and angular distribution pattern. Radiation coming from the radiator can be splitted into two different orthogonal paths, one for each measure, by means of a conventional beam splitter, as far as optical radiation is concerned. This configuration has not been used in the preliminary measures since we had no experimental knowledge on photons budget and background noise. Therefore the measure of the beam image and the angular pattern have been performed in separate sessions and with different configurations.

To ensure the proper alignment of the optical elements with respect to the beam direction, the light coming from the thermoionic cathode and reflected from the metal foil was used to define the axis of the optical path. The beam has been then steered to intersect the light spot on the foil. The alignment accuracy is of the order of 0.1 mrad. The image of the cathode has been removed from the radiation measures along with the background noise.

Two detectors has been used according to the expected and measured light level. Beam image acquisition has been accomplished using a conventional CCD monochrome camera with a sensitivity of 0.3 lux coupled to a 50 mm objective. The angular distribution pattern has been measured using an intensified camera with a sensitivity lower than 3 order of magnitude with respect to a conventional camera.

The spatial limit resolution of these detectors has been measured on a test bench in term of Modulation Transfer Function. A value of 12 line pairs for mm has been found which gives a limit resolution of the order of 80 μm.

Both camera types transfer frames according to the RS-170 standard. A workstation based on an NT PC acquires images using a frame grabber and allow the storage and the real time analysis of the main characteristics of the beam. A LabVIEW based application has been developed for this purpose.

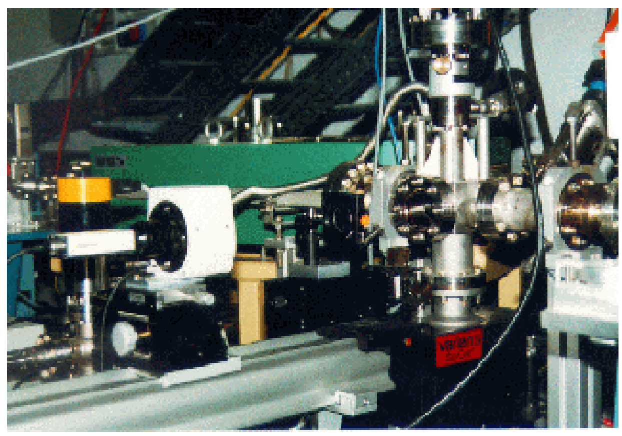

Fig. 2 Experimental set-up

MEASUREMENTS

The system so far described has been used during two shifts in September 1996 and March 1997. The first set of measurements has been devoted to the set up of the whole optical chain and to the measure of the light budgets. OTR beam images has been taken over the whole range of energies with bunches of 16 nC and 70 ns length. Conventional CCD camera sensitivity have been showed adequate to ensure beam profiles with an overall resolution of 0.1 mm, which is close to the intrinsic detector limit. OTR images are better defined than Chromox 6 images taken for comparison purpose at the same point and on the same beam as the difference at FWHM is of the order of 20%. This is due mainly to the lack of light contribution due to volume effects which take place in alumina or fused silica screens. Fig. 3 shows an OTR beam image at 50 MeV.

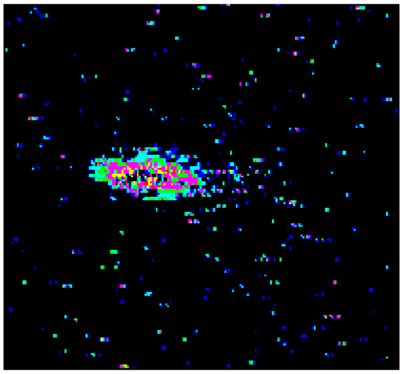

Fig. 3 OTR beam image at 50 MeV

Measurements of the angular distribution pattern have been done using both a conventional camera and an intensified camera at 100 MeV using a C-mount 50 mm objective. The sensitivity provided by the conventional camera has been satisfactory due to the small aperture of the angular pattern. Nevertheless the use of the 50 mm objective gives poor spatial resolution in the image and a real infinite focusing condition may not be achieved.

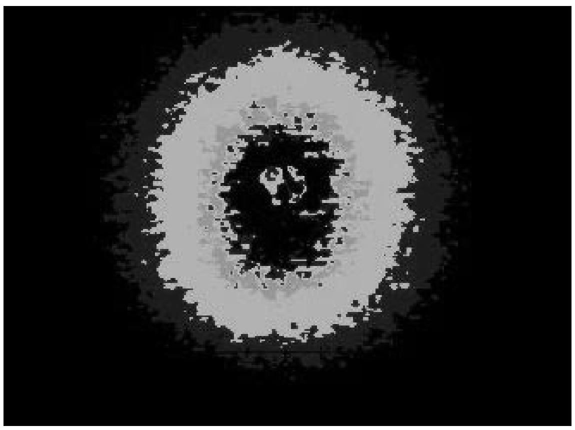

Fig.4 OTR angular pattern at 60 MeV

The second shift has been devoted to a deep study of the relations between peak distance and energy. The optical arrangement has been based on a movable lens of 125 mm focal length and 40 mm diameter and the intensified camera has been used as the detector. The magnification factor provided by the optics has been chosen so that this arrangement allows to make measurements over the whole energy range with the same ratio pixel/mm. This allows a comparison between patterns referred to different energies. Infinite focusing has been defined as the position of the lens relative to the camera CCD which focuses the reflected image of the thermoionic cathode on the radiator (this distance is of the order of 25 meters). Particular care has been devoted to the choice of the camera gain in order to work in linear gain region.
Fig. 4 shows OTR pattern at lens focal plane. The electron energies was 60 MeV. The OTR pattern is ideally a cone with the peak intensity at an angle of approximately 1/c about the direction of specular reflection. The low divergence of the electron beam results in the well defined central null intensity, which gives the "doughnut" shaped pattern observed.
Fig. 5 shows the measured values of the peak distances as function of $1/\gamma$. The relation is linear as expected.

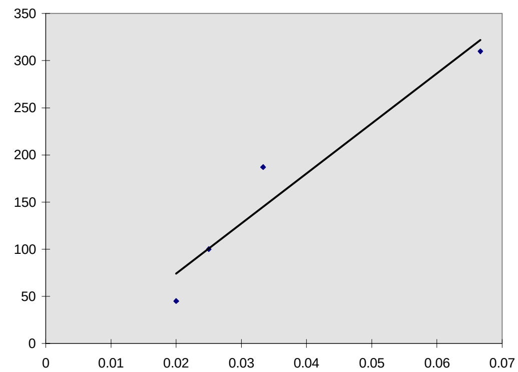

Fig. 5 OTR Peaks Distances vs. 1/γ

CONCLUSIONS

The preliminary measurements above discussed have shown that the experimental setup installed at the Elettra Linac would provide extensive data on OTR emission. Measurements of beam divergence from OTR angular pattern and analysis of the behaviour of different screen materials and thickness will be carried out during 1997.

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