OTR Measurements for the TTF Commissioning

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Abstract

OTR based energy spread and emittance measurements performed in the first stage of the TTF beam commissioning are reported.
Using a gatable intensified camera, beam position and profile, as well as emittance, evolution along the macrobunch has been investigated.

1 -Introduction

The TESLA Test Facility (TTF) is a 500 MeV Superconducting Linac in costruction at Desy Laboratory (Hamburg) by an international collaboration aimed at establishing operative conditions for accelerating structures with gradients above 15 MeV/m [1]. As a test bench for the TESLA linear collider, an 800 μsec, 8 mA beam will be provided by two different injectors: injector I, which is actually operative, gives the required current and bunch length at a microbunch frequency of 216 Mhz, with 37 pC/micropulse, while the injector II, which is now under test at Fermilab and will be installed at Desy early next year, will provide the same average current at 1 MHz micropulse frequency, with 8 nC/micropulse. Stable operation with long, high charge, macropulse is the basic need for a Superconducting Linear Collider, and is one of the main features to be tested on TTF. The requirement for time resolved measurements, toghether with the relatively high charge of the beam, make Optical Transition Radiation (OTR) a natural choice for beam diagnostics. It must be noted that TTF is the first accelerator for which OTR has been considered from the design stage as one of the main diagnostic tools.
Nine optical diagnostic stations have been installed in the temporary transport channel and in the experimental area. Five of them consist of a ceramic screen, an OTR mirror and a stainless steel screen with precise reference marks for the calibration of the optics and imaging system. The three screens are mounted on a single shaft whose movements is driven by a stepping motor. Due to the directivity of the OTR radiation, much care has been put in preserving the screen tilt angle while moving it. Laboratory measurements show a constant reflection direction within 200 μrad.
To help operators in the first beam transport, simple low cost CCD camera have been installed on all the stations. The strong radiation due to beam losses have damaged them in a short time. At beamline positions where quantitative measurements are required, we are now installing small optical table with heavy lead shields. On the table find place the camera and all the optics (lenses, filters etc), mounted on remotely controlled movements.
These safe conditions allow a Princeton Instruments ICCD intensified camera to be used. Its high quality CCD is Peltier cooled, and the resulting S/N ratio, together with a low digitizing rate, gives a full 12 bits dinamic range, with even a single photon clearly visible.
A gate on the electron multiplier, whose width can be as short as 200 nsec, allows time resolved measurements. We have used an integration time of 1 μsec that, when injector II will be operational, will allow to perform single micropulse measurements.
The camera was extensively tested in laboratory, and no effects on spatial resolution from either gain or ligth intensity was observed.

2 - Experimental results

In the first stage of TTF commissioning no particular efforts have been dedicated to optimisation of the beam quality, limiting ourselves to transport the beam to the final dump. More work has been devoted to the setting up of the cryomodule. The beam measurements performed so far were mainly intended to test the diagnostics, both hardware and software.
All measurements were carried out with a 35 μsec long macropulse, the only one allowed by the interlock system with actual transport conditions. We have also worked with a beam current varying from the design value of 8 mA to as low as 2 mA, due to cathode reduced efficiency.
Using a standard CCD camera we have measured beam energy spread and emittance, integrated on the whole macrobunch. The OTR intensity was high enough to saturate the camera’s signal, requiring a reduction of the iris aperture.
With the intensified camera we have measured beam position and profile evolution along the macrobunch at the injector level. We have repeated the same measures in the experimental area, adding also the measure of the emittance time behavior.

2.1 - Integrated measurements

Energy spread was measured in the dispersive section at the end of the transport line. The measured values resulted very sensitive to the setting of the subharmonic prebuncher, that presents an initial transient due to beam loading difficult to

compensate. Fig 1 shows a result obtained with a good transient compensation.
Emittance was measured with the variable gradient methode, changing the strength of a quadrupole doublet in front of an OTR screen in the experimental area. For each current value, 10 images were taken, in order to estimate the error due to bunch to bunch fluctuations.

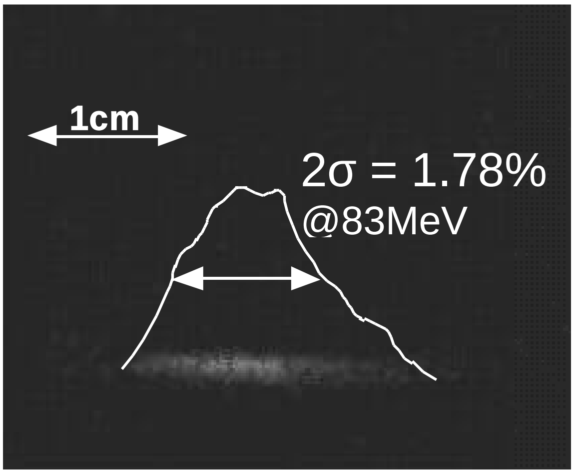

Fig. 1 - Energy spread measured with a good compensation of the subharmonic prebuncher transient

Images were filtered to eliminate the “salt and pepper” noise due to higher energy radiation, and the rms spot dimensions in the horizontal and vertical plane were calculated for the points inside a closed equilevel curve containing a defined percentage of the total intensity. With these calculations, aimed to eliminate the strong contribution to the rms value of the extreme tail, we tried also to investigate the presence of a different behavior of the beam core respect to its halo.
The rms emittance value resulting from this analysis, shown in Fig. 2, is much larger than that measured, at a different time and with different conditions, at the injector output [2]. There are many possible sources for this emittance degradation, that will be analyzed during the next accelerator run.

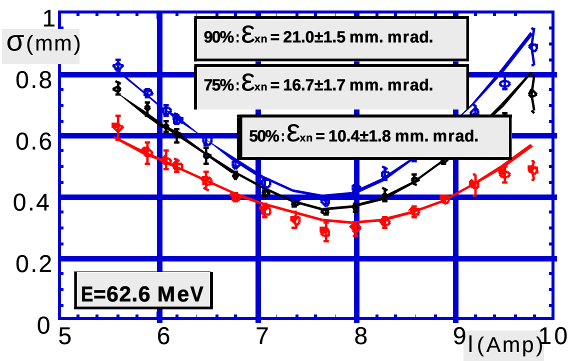

Fig. 2 - Horizontal beam spot size (rms) as a function of the doublet current and related normalized emittances for different percentage of the total intensity

2.2 - Time resolved measurements

With the intensified camera, we have performad an analysis of beam position and profiles evolution along the macrobunch in the injector section, using an OTR station installed by the Orsay collegues after the capture section. An initial transient of approximately 8 μsec due to the prebuncher beam loading was clearly visible as both a beam position drift and a size variation. After this transient the beam dimension stabilises but, as can be seen in Fig. 3, a small vertical oscillation is still present.

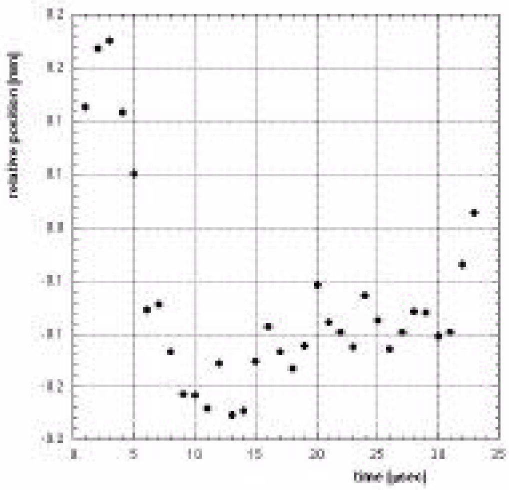

Fig. 3 - Vertical beam centre evolution along the macropulse in the injector zone

A Fourier analysis (see Fig 4) shows a well pronounced line at 250 kHz. After a better setting of the capture section parameters and a more accurate beam alignment, this effect disappeared.
The same measurement has been performed in the experimental area, with the full energy beam.

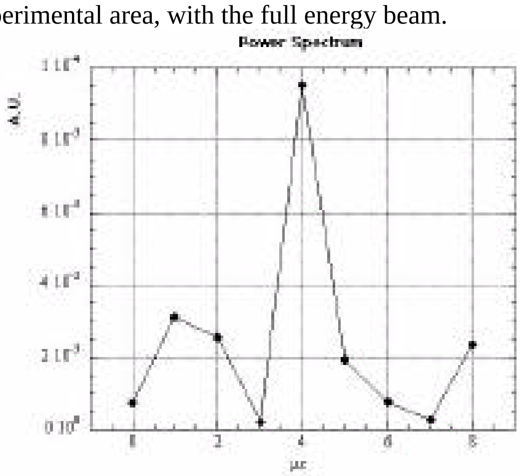

Fig. 4 - Fourier analysis of the beam position of Fig.3

At that moment, only five cavities were operational, so we were limited in energy at, approximately, 70 MeV.

Fig. 5 shows the behavior of the horizontal and vertical beam size. The initial transient due to the prebuncher is still present, but after that the beam is no more stable. In the particolar focusing conditions of Fig. 5, the beam is round at the beginning and at the end of the macropulse, while a larger vertical size is evident in the middle.

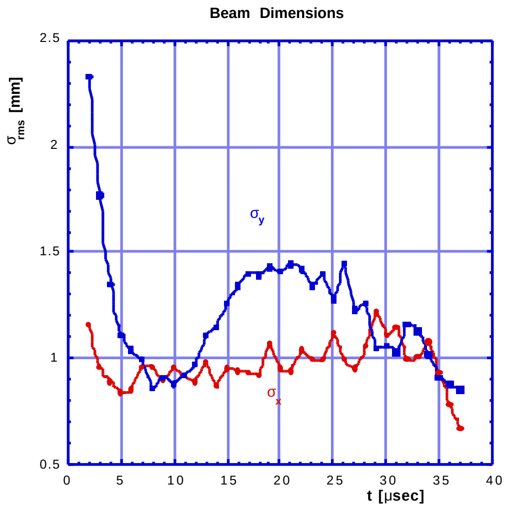

Fig. 5 - Evolution along macropulse of the horizontal and vertical beam size (rms)

Emittance was measured for ten time slices 1 μsec long separated by 4 μsec each, thus covering the whole macrobunch length. For each value of the doublet current, five time scans were performed in order to avoid too large errors due to bunch to bunch fluctuations. It was not possible to find a single doublet current range for which a waist in both the horizontal and vertical plane was present, and we were forced to perform two distinct measurements with respectively positive and negative currents. The source of this strong asymmetry in the phase space of the two planes must be further investigated.

Fig. 6 shows a typical behavior of the horizontal rms beam size as function of the doublet current. The solid line is the result of the fit with the transport matrix.

The time evolution of the horizontal rms normalized emittance, for different beam spot intensity selections, as described previously, is shown in Fig. 7.

The emittance is almost linearly increasing with time, but the slope is lower for the beam core, indicating that time dependent effects influence mainly the beam halo.

It is not clear, at the moment, if the large value of the beam emittance and its longitudinal non uniformity is the consequence of either the transit in the accelerating module in which three of the total eight cavities, being detuned but cooled, could trap high order modes, or depends on non linear effects due to a bad transport to the experimental area.

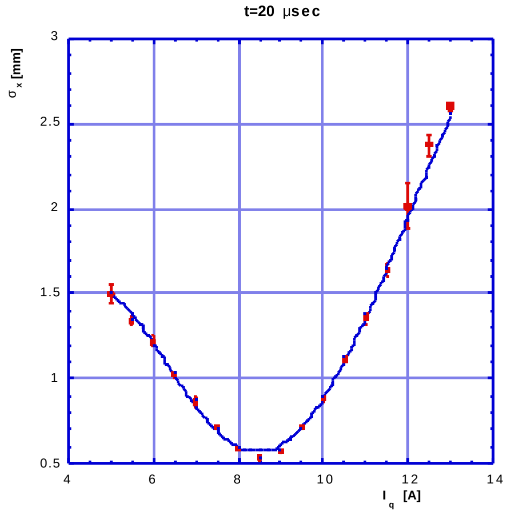

Fig. 6 - Typical behavior of beam spot size as function of the doublet current

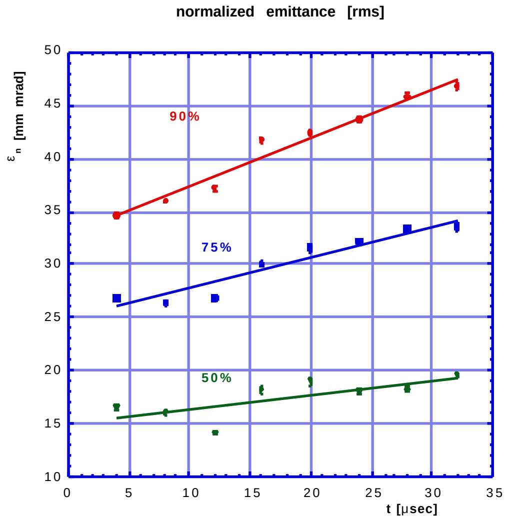

Fig. 7 - Evolution of rms normalized emittance along macropulse for different fractions of beam intensity

With our diagnostic instruments now extensively tested, we could perform, in the next run, a systematic analysis of the possible sources of emittance dilution.

References

1) - TTF Conceptual Design Report - TESLA 95-01, Desy 1995

2) - A. Variola et al. - Measurements of the TTF Injector Beam Characteristics using Electromagnetic Radiation in the Optical Range - These Proceedings