EMITTANCE AND DISPERSION MEASUREMENTS AT TTF

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Abstract

It is well known that beam dispersion , along with the Twiss parameters and emittance, contributes to the beam spot size. So that, in general, anomalous dispersion is an undesirable event and must be minimized by careful tuning the machine. If not, when the spot size is used to infer beam emittances, as it is the case of the ”quadrupole scan” method, basically employed at TTF, the unknown dispersion can lead to overestimated values for the emittance. This paper presents the first attempt to determine the dispersion function at several points of the TTF Linac and to separate its contribution to the local emittance measurement, performed by means of the OTR imaging technique.

1 INTRODUCTION

Since the beginning of this year, TESLA Test Facility (TTF) is operated with Injector II equipped with a laser driven rf gun. Injector II is designed to generate electron beams with an emittance of 20 mm mrad (normalized) at a bunch charge of 8 nC , an option needed for a TESLA Linear Collider, and with an emittance of 2 mm mrad at 1 nC in a FEL mode [1]. In both cases it is important to preserve emittances as small as possible up to the end of the linac. For this purpose the beam emittance is monitored at several points along the accelerator.

The results of the TTF commissioning with Injector I have shown that, while at the injector level the measured values for the emittance were in agreement with designed specifications, in the high energy region of the linac a certain emittance growth was observed. Measurements were performed by means of the ”quadrupole scan” method in which the rms beam size is measured as a function of the strength of one or several quadruples situated upstream a beam profile monitor. Since in this method the beam size is used to infer beam emittances, there are suspicions that an unknown dispersion could contribute to the beam spot size, thus leading to overestimated values for the emittance.

In practice, the beam dispersion arises due to misalignment of beam line elements or off-axis beam transporting. Once generated at some place, it will propagate through the machine. In general, an anomalous dispersion is an undesirable event, since it can significantly increase the beam size at places where that is expected to be particularly small: at interaction points of colliders or undulator sections of FELs. Careful tuning the machine is sometimes needed to minimize the beam dispersion.

This paper presents the first attempt to determine the dispersion function of the TTF Linac. Measurements were performed by means of the OTR imaging technique widely employed at TTF [2]. Two different kind of dispersion measurements were done at two positions of the linac.

2 DISPERSION AND EMITTANCE MEASUREMENT BY MULTIPLE ”QUADRUPOLE SCAN” .

At the position between first and second acceleration modules, after the so-called ”bunch compressor II”, we attempted to determine simultaneously the beam emittance and both the spatial and angular dispersions by means of a multiple scan. A schematic diagram of a layout is shown

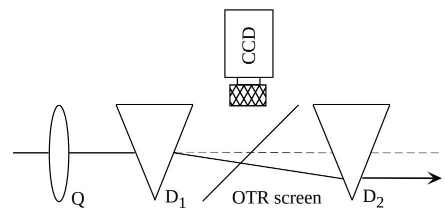

Figure 1: Schematic layout for multiple scan dispersion and emittance measurements.

in Fig. 1. A quadrupole Q followed by a bending dipole D_1 allowed to change the beam spot on a OTR screen, images of which were registered by a CCD camera. A second dipole D_2 behind the screen was employed to drive the beam through the second acceleration module and, thereby, prevent quenches in superconducting cavities due to the beam dumping inside the cryomodule.

As known, in the presence of the dispersion the first-order squared beam size on the screen is given by

$$x_{rms}^2 = \sigma_{11}(s) + \left(\eta(s)\frac{\Delta p}{p}\right)^2 , \qquad (1)$$

where $\sigma_{ij}(s)$ stands for elements of the σ- matrix defined at the position s (OTR screen), $\eta(s)$ is the dispersion function at this position and $\Delta p/p$ is the momentum spread. In the linear optics, an evolution of the σ- matrix from point to point of the beam line is controlled by the transfer matrix. In particular, the transformation of the element σ_{11} from the entrance face of the quadrupole Q (position 0) to the position s is described as follows

$$\sigma_{11}(s) = m_{11}^2\sigma_{11}(0)+2m_{11}m_{12}\sigma_{12}(0)+m_{12}^2\sigma_{22}(0), \qquad (2)$$

where m_{ij} denotes elements of the 3×3 transfer matrix. In the same manner, the dispersion function on the screen is determined by its value and derivative at the entrance of the quadrupole

$$\eta(s) = m_{11}\eta(0) + m_{12}\eta'(0) + m_{13} . \qquad (3)$$

The element m_{13} of the transfer matrix is the lattice dispersion produced by the dipole D_1 that adds on to the beam dispersion when the beam passes through the dipole. Substituting Eqs. (2) and (3) into Eq. (1), we get

$$x_{rms}^2 = m_{11}^2 a_1 + 2m_{11}m_{12}a_2 + m_{12}^2 a_3 \\ +2m_{12}m_{13}a_4 + 2m_{12}m_{13}a_5 + m_{13}^2 a_6 \,. \quad (4)$$

In [3], Eqs. (1)-(3) were exploited to simultaneously obtain the emittance, beam dispersions and other beam parameters, by measuring the rms beam size at different focusing fields, followed by solving a corresponding set of nonlinear equations. Meanwhile, Eq. (4) reveals that by appropriate combinations of the initial beam parameters to be found, the problem becomes linear with respect to new parameters a_i:

$$\begin{aligned} a_1 &= \sigma_{11}(0) + \eta(0)^2 r^2 \,, \\ a_2 &= \sigma_{12}(0) + \eta(0)\eta'(0) r^2 \,, \\ a_3 &= \sigma_{22}(0) + \eta'(0)^2 r^2 \,, \\ a_4 &= \eta(0) r^2 \,, \\ a_5 &= \eta'(0) r^2 \,, \\ a_6 &= r^2 \,, \\ r &= \Delta p/p \,. \end{aligned} \quad (5)$$

In this case a least-squares fitting algorithm may be easily applied if one makes the beam size scan by varying the strength of the quadrupole. However, one should bear in mind that if m_{13} is equal to zero, it is impossible to separately obtain from the fit elements of the σ- matrix and dispersions. If m_{13} is kept constant, in principle, all the parameters may be resolved, but the method does not seem quite reliable due to possible inaccuracies in measurements. The best fashion is to measure several scans when m_{13} is changed from scan to scan (by varying the dipole field). Then a_i and, hence, beam parameters are found by applying a single fit to all scans. As minimum, two scans are necessary. Once the σ-matrix is estimated, the beam emittance is found according to the formula

$$\varepsilon = \sqrt{\sigma_{11}(0)\sigma_{22}(0) - \sigma_{12}^2(0)} \quad (6)$$

Results of the practical realization of the described method are shown in Fig. 2, where two scans of the squared rms beam size for two different dipole current of $1.1A$ and $-5.0A$ are given. Measurements were performed for the horizontal plane only. The effect of the dipole field change was detected as a quite measurable shift of the scan curve. However, when applying the least-squares fit to the both curves we found that it was impossible to estimate correctly a momentum spread from the data. We identified this failure with a smallness at used dipole currents of the last term in Eq. (4) compared to others. In fact, in the linear model an exceedingly small value of m_{13}^2 provokes an unacceptably large value for a_6 that is the squared momentum spread.

Due to the fact that there was no tool available at the position to measure this parameter it was taken as a variable in the fit.

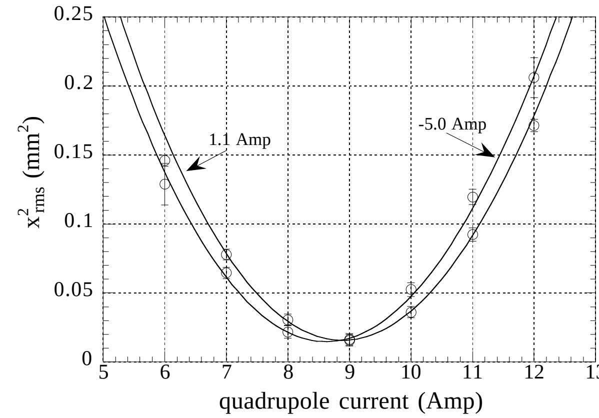

Figure 2: Two quadrupole scans of the squared rms beam size for two different values of the dipole current together with the least-squares fit to the data.

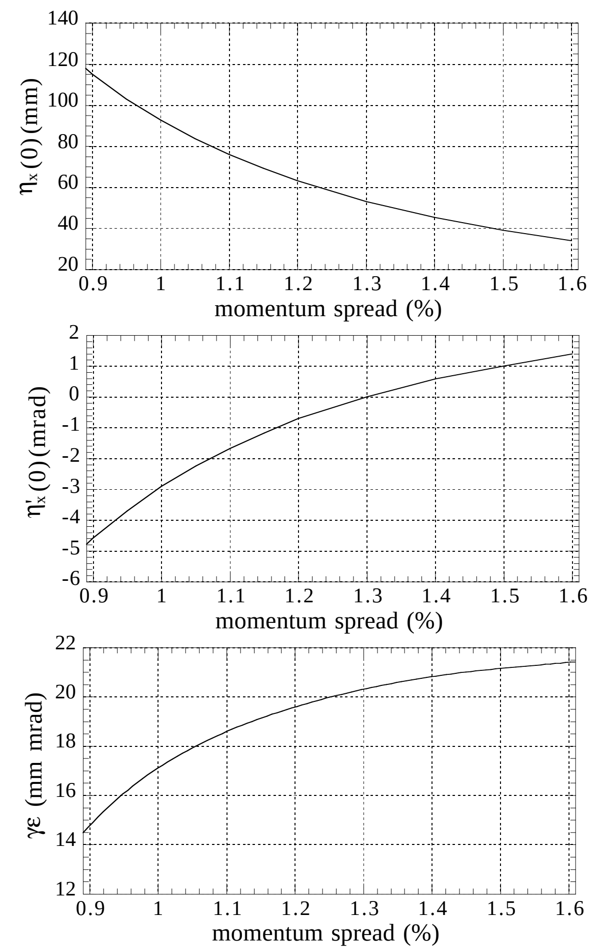

Figure 3: The spatial dispersion, angular dispersion and normalized emittance in the horizontal plane versus the momentum spread.

Fig. 3 plots the fit estimations for the spatial and angular dispersion together with the normalized emittance versus the momentum spread that is varied around its "default" value of 1%. Emittance estimations are quite consistent with a value of about 20 mm mrad that was measured at the injector level by a multislit mask method for the 8 nC bunch charge. From this comparison we conclude that the momentum spread was likely larger then 1.25%, that is, in turn, in agreement with the measurement of the total beam energy variation along the macropulse found to be of the order of 5% [4]. Finally, the following limits for the dispersions can be given: $\eta_x(0) < 60$mm; $\eta'_x(0) < 2$mrad.

3 DISPERSION MEASUREMENT BY BEAM ENERGY VARIATIONS

This standard technique is based on the definition of the spatial dispersion

$$\eta = \frac{\Delta x}{\Delta E/E} \tag{7}$$

and consists in the measurement of the transverse beam displacement Δx when stepping the beam energy in a small range ΔE about its nominal value E.

The measurement was carried out in the experimental area. An energy variation of $\pm 1.54\%$ was effected by adjusting the rf system. Transverse beam positions were obtained as centers of gravity of beam spot profiles registered by the OTR beam profile monitor. To make it possible to derive both the dispersion function and its derivative, measurements were repeated for three different values of the quadrupole strength of a doublet situated 1.4 m upstream the OTR screen. For every rf and quadrupole strength settings, 40 beam images were recorded to provide a better statistics. Beam positions were obtained by averaging over all images, and beam displacements by averaging over different beam energies. Nevertheless, it turned out to be impossible to get data for the vertical plane, because the beam size in this plane was unacceptably large to reliably detect the small beam displacement.

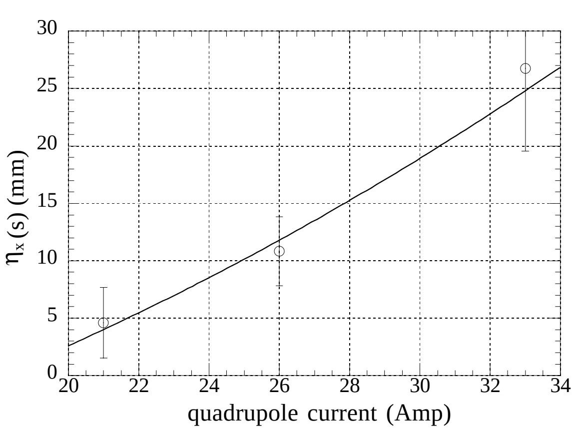

Figure 4: Spatial dispersion in the horizontal plane versus the quadrupole current and least-squares fit to the data.

Fig. 4 shows the horizontal spatial dispersion at the position of the screen as a function of the quadrupole current. To infer both the spatial and angular dispersions a fit must be applied to the $\eta(s)$ measurements. By making use of Eq. (3) with $m_{13} = 0$, these quantities can be found at the entrance of the doublet. A least-squares fit to the data shown in Fig. 4 gives following estimations for the dispersions: $\eta_x(0) = 12.7$mm; $\eta'_x(0) = 0.9$mrad.

4 CONCLUSIONS

The first attempt to determine the beam dispersion and to study its effect on the beam emittance was undertaken at TTF. Two different measurements were performed at two positions of the linac.

By the multiple quadrupole scan method we found upper limits for the dispersion and emittance at the position of the bunch compressor II based on an assumption about the momentum spread. In the experimental area we performed the dispersion measurement by the beam energy variation.

5 REFERENCES

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