THE SCIENCE AND CULTURE SERIES PHYSICS

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Proceedings of the 46th Workshop of the INFN ELOISATRON Project

THE PHYSICS AND APPLICATIONS OF HIGH BRIGHTNESS ELECTRON BEAMS

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L. Palumbo • J. Rosenzweig • L. Serafini

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Erice, Italy 9 — 14 October 2005

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PREFACE
THE PHYSICS AND APPLICATIONS OF HIGH BRIGHTNESS ELECTRON BEAMS

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The ICFA-sponsored (ICFA Panel on Beam Dynamics, ICFA Panel on Advanced Accelerators) workshop on "The Physics and Applications of High Brightness Electron Beams" was held on October 9-14, 2005, in Erice, Sicily, Italy, at the Ettore Majorana Foundation and Center for Scientific Culture (EMFCSC). It was the 46th Workshop of the Series "INFN Eloisatron Project".

We had a fine international representation from the fields of intense electron sources, free-electron lasers, advanced accelerators, ultra-fast laser-plasma, beam-plasma and laser-beam physics, well according to the tradition of this workshop series, built up on the heritage coming from the merging of two ICFA-sponsored series, one on high brightness beams, and the other on free-electron laser physics. The most recent high brightness beam workshop was entitled "The Physics of High Brightness Beams", endorsed by the ICFA Panel or Novel and Advanced Accelerators, and was held in Los Angeles in November 1999. It concentrated on the emerging physics of intense beam systems, and was notable for the exciting synthesis of methods and concepts between electron beam and ion beams. On applications side, the final installment "Arcidosso Series" of workshops, held in Sept. 2001, was entitled "The Physics of, and Physics With, the X-ray Free-Electron Laser". This title foreshadows the merging of discussions between the physics of the enabling device (in this case the FEL), with the examination of the physics of the enabled applications. The first workshop merging the two series was held in July 2002 in Sardinia (Italy): the proceedings are available from World Scientific*.

As for the previous one, the mission of this workshop was stated by the increasingly critical role that high brightness electron beams are playing in two frontier fields: radiation generation methods and advanced acceleration schemes. Such state-of-the-art radiation production methods include various types of free-electron lasers, as well as inverse Compton scattering (ICS) of intense lasers, having diverse approaches to creating high peak and average power light sources. As they are capable of harder photon production, ICS sources are candidates not only for X-ray sources, but also high-energy physics applications. Likewise, high brightness beams are at the center of future accelerator schemes, e.g. based on high gradient wakefields, and electron cooling. Indeed, possibilities exist to create unique light sources based on advanced acceleration schemes, just as intense light sources enable advanced accelerator research. The goal of this workshop is to provide a comparative study of the generation, manipulating, modeling and measuring of high brightness electron beams, and the underlying methods linking the physics of these beam systems to the physics of advanced applications.

The workshop would not have been a success without its working group leaders (M. Ferrario, G. Travish, L. Giannessi, M. Uesaka) and their scientific secretaries (D. Filippetto, G. Gatti, A. Schiavi, A. Rossi).

Further debts are owed to the workshop local organization (Rossana Centioni, Silvia Giromini and Mary Jo Robertson), the EMFCSC local team (Fiorella Ruggiu and Pino Aceto), the program committee (C. Pellegrini, W. Barletta, M. Ferrario, P. Emma, D. Dowell, L. Giannessi, J. Murphy, P. O'Shea, J. Rossbach, T. Garvey, M. Eriksson, G. D'Auria, D. Giulietti), and the organizing committee (L. Palumbo, J. Rosenzweig, L. Serafini, G. Krafft, H. Braun, K-J. Kim, S. Bertolucci, I. Ben Zvi, A. Renieri, S. Milton, S. Chattopadhyay, J. Galayda, M. Poole, C. Bocchetta, K. Floettmann, P. Krejcik).

But it's certainly with Prof. A. Zichichi, President of the Ettore Majorana Foundation and Center for Scientific Culture, that we are mostly indebted: thanks to his kind invitation to join the "INFN Eloisatron Project" workshop series, all our participants could enjoy a unique combination of a fascinating land to visit, Sicily, an enchanting town to live, Erice, and a world-wide famous Center of Science and Culture, EMFCSC, to host the workshop activities.

Sicily, the largest island in the Mediterranean sea, displays spots of extreme nature, made of fire and volcanos, as well as marvellous beaches and sea landscapes. Its history is full of culture and merging civilizations, from

* "The Physics and Applications of of High Brightness Electron Beams", Ed. J.B. Rosenzweig, L. Serafini and Gil Travish (World Scientific, Singapore, 2003).

Phoenicians to Greeks, from Romans to Normans: a fusion whose the village of Erice is one of the best example. It is in the context of such a poetic and inspirating environment that EMFCSC developed through the last 43 years an impressive amount of scientific culture, making a deep impact within the world scientific community.

We hope that these proceedings give some flavor of the workshop plenary presentations and the discussions within the working groups, and also that they provide a unique reference to the status of the relevant research fields as well as their development into the future.

Luigi Palumbo
Rome

James B. Rosenzweig
Los Angeles

Luca Serafini
Milan

September 2006

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Plenary Sessions

RF DEFLECTOR BASED SUB-PS BEAM DIAGNOSTICS: APPLICATION TO FEL AND ADVANCED ACCELERATORS†

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RF deflectors are very promising devices for longitudinal and transverse phase space characterization and beam manipulation in advanced accelerators. Measurement setups for longitudinal pulse shape as well as phase space and transverse beam slice emittance characterizations are described as well the main design criteria of traveling wave and standing wave RF deflectors used for beam diagnostics putting in evidence the advantages or disadvantages of the two devices in terms of performances, required power and power limitations.

1. Introduction

The characterization of the longitudinal and transverse phase space of the beam at the end of an injector is a crucial point in order to verify and tune all photoinjector performances. With the use of an RF deflector (RFD) it is possible to measure the bunch length [1,2] and, adding a dispersive system, the longitudinal beam phase space. Similarly, since the longitudinal beam distribution can be projected along a transverse coordinate, the transverse emittance of each longitudinal bunch slice can be measured using the quadrupole scan technique [3-5]. In the first section of the paper I shortly review the basics principles of the longitudinal and transverse beam phase space characterization using an RFD. In particular I illustrate the bunch length measurement and the sources of errors (par. 2.1), the longitudinal phase space characterization (par. 2.2) and the horizontal beam slice emittance measurement (par. 2.3). The possibility to obtain ultra short bunches with the use of two RFDs is described in par. 2.4 while the diagnostics with a circular polarized RFD is illustrated in par. 2.5. The second section of the paper is centered on the RFD structures. In particular I refer to the traveling wave devices (par. 3.1), to the standing wave devices (par. 3.2) and I compare the two structures in term of performances (3.3). In the par. 3.4 I address the RF measurements that can be done with an

† This work has been partially supported by the EU Commission in the sixth framework programme, contract no. 011935 EUROFEL-DS1.

RFD and (on par. 3.5) I discuss the power systems. The already obtained experimental results are finally summarized in par. 4.

2. Beam diagnostics and manipulation using RFD

The different types of measurements that can be done with RFDs are based on the property of the transverse voltage[1] (V_T) to introduce a correlation between the longitudinal coordinate of bunch and the transverse one (Fig. 1). The phase of the deflecting voltage is tuned in order to have zero crossing[2] of V_T in the center of the bunch giving a linear transverse deflection from the head and to the tail of the bunch. After the deflector the transverse kick (vertical, for example) results into a transverse displacement of the centroid of each bunch slice, proportional to the slice longitudinal position with respect to the bunch center.

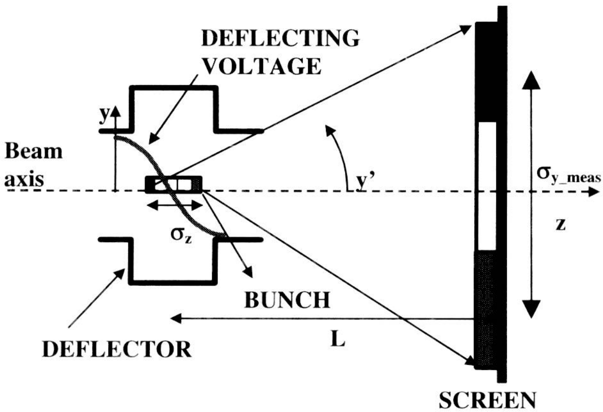

Figure 1. Longitudinal to transverse correlation induced by the RFD transverse voltage.

2.1. *Bunch length measurements*

The relation between the z longitudinal component within the bunch (z=0 corresponds to the bunch center) and the vertical position y on the screen is given by:

$$y = R_{34}\frac{V_T}{E/e}\sin\left(\frac{\omega_{RF}}{c}z+\varphi_{RF}\right)\underset{z<<\lambda_{RF}}{\cong} R_{34}\frac{V_T}{E/e}\sin\varphi_{RF} + \underbrace{R_{34}\frac{V_T}{E/e}\frac{\omega_{RF}}{c}\cos\varphi_{RF}}_{K}\,z$$

(1)

[1] The integrated transverse Lorenz force per unit charge.

[2] As illustrated in the following paragraphs this condition is not strictly necessary.

where ω_{RF} is the angular frequency of the deflecting voltage, $V_\perp$ is the peak transverse voltage, E is the beam energy in eV units, φ_{RF} is the RF phase with respect to the bunch passage (at perfect zero crossing $\varphi_{RF}=0,\pi$) and R_{34} is the optical transfer function given by:

$$\begin{cases} R_{34} = \sqrt{\beta_{y\_defl}\beta_{y\_screen}}\sin \Delta\Phi & \text{(general expression)} \\ R_{34} = L & \text{(simple drift space)} \end{cases}$$

(2)

where β_{y_defl} and β_{y_screen} are the vertical β-functions at the deflector and screen position, respectively, $\Delta\Phi$ is the phase advance between the deflector and the screen and L is the drift space of length L.

The position of the bunch centroid on the screen ($\bar{y}$) and its rms value (σ_y) are given by[3]:

$$\bar{y} \cong R_{34}\frac{V_T}{E/e}\sin\varphi_{RF}$$

(3)

$$\sigma_y \cong \underbrace{\left|R_{34}\right|\frac{V_T}{E/e}\frac{\omega_{RF}}{c}\left|\cos\varphi_{RF}\right|}_{|K|}\sigma_z$$

(4)

Equations (1)-(4) show that the longitudinal bunch distribution can be measured by measuring the transverse bunch distribution after the deflector.

In particular, looking at the previous equations, it is possible to directly calibrate the screen vertical coordinate measuring the bunch centroid position $\bar{y}$ on the screen for different values of the RFD phase φ_{RF} by assuming $|\sin\varphi_{RF}|<<1$. Looking, for example, at the case $\varphi_{RF}<<\pi$, from the previous expressions one has, in fact, that:

$$\bar{y} \cong R_{34}\frac{V_T}{E/e}\varphi_{RF} = \underbrace{R_{34}\frac{V_T}{E/e}\frac{\omega_{RF}}{c}}_{K'}z$$

(5)

The calibration coefficient *K'* multiplied by $\cos\varphi_{RF}$ is equal to the coefficient *K* that I have pointed out in equation (1) and (4) that gives the scaling factor between the screen coordinate y and the longitudinal position z.

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[3] From now I suppose that is always satisfied the relation: $z<<\lambda_{RF}$.