ELECTRON BEAM DYNAMICS IN CERN-PSI-ELETTRA 5π/6 TRAVELING WAVE X-BAND LINEARIZER.

M. El Ashmawy, S. Di Mitri, G. D'Auria, Sincrotrone Trieste ELETTRA, Italy.

Abstract

The 4th Generation Light Source FERMI@ELETTRA, in construction at the ELETTRA Laboratory in Trieste, requires very short electron bunches at the entrance of the undulator chain. To linearize the longitudinal phase space in the presence of the compression process, a 4th harmonic decelerating section (11992 MHz) will be installed before the first magnetic chicane. An X-band structure, with integrated alignment monitors [1], is currently under development in the framework of collaboration between CERN-PSI-ELETTRA. In this paper we will present a full longitudinal and transversal beam dynamics of the electron beam along the X-band structure during linearization process using 3D space charge code TStep [2]. Beam dynamics simulations will also be continued along the whole FERMI linac using *elegant* code [3].

INTRODUCTION

The future FERMI@ELETTRA single pass FEL facility in the spectral range 100-4 nm [4] foresees an ultra short and high quality electron beam needed at the entrance of the undulators. Figure 1 shows the proposed linac layout for the two phases of the project: FEL-I (100-40 nm) and FEL-II (40-4 nm).

In the context of achieving such high quality bunches, the electron bunch in its trip from the RF gun till the undulators is subjected to successive stages of acceleration and compression and is affected by many collective effects allowing for single bunch instabilities such as space charge effect, wake fields and coherent synchrotron radiation (CSR). The final compressed bunch is mainly dominated by non-linear effects such as RF time curvature and the second order path-length dependence on particle energy. In the magnetic compressors chicane, the second order path-length term has the same sign of the effect of time curvature, which lead to very sharp temporal spikes in the final beam current after compression. These spikes may derive beam instabilities due to coherent synchrotron radiation (CSR) in the chicane which can damage seriously the transverse emittance and energy spread. In the framework of retaining the desired temporal bunch profile at the undulator entrance, the undesired collective effects could be compensated using a short section of RF structure working in deceleration mode and operating at higher harmonic of the main accelerating sections [5-8]. In FERMI@ELETTRA, an X-band structure is embedded in a chain of S-band linacs as shown in Fig.1 to linearize the longitudinal phase space of the electron beam [9].

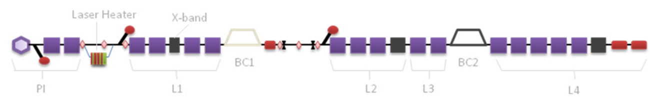

Figure 1: Schematic layout of the beam line for the FEL-I and FEL-II stages at FERMI@ELETTRA

The energy reduced due to deceleration process (E_x) in MeV by X-band linac during the linearization of the longitudinal phase space is evaluated [7] by the following equation with little modification:

$$E_x = \frac{E_{fo}\left\{1+3\left(\frac{\lambda_s}{2\pi}\left(1-\frac{\sigma_f}{\sigma_0}\right)\Big/R_{56}\right)^2\right\}-E_i}{\left(\lambda_s/\lambda_x\right)^2-1} \qquad (1)$$

Here E_i = 4.7 MeV is the initial electron bunch energy after the RF gun; E_{f0} = 230 MeV is the designed electron beam energy at BC1; σ_f / σ_0 = 0.287 is the BC1 compression ratio; R_{56} = 0.03 m is the BC1 momentum compaction coefficient and λ_s & λ_x are the wavelengths at the S-band (2998 MHz) and X-band (11992 MHz) respectively. Accordingly, the energy needed to be decelerated by the high harmonic structure equals approximately to 20 MeV.

X-BAND LINAC DESCRIPTION

The design of the constant gradient X-band structure used in FERMI@ELETTRA employs 5π/6 phase advance geometry which integrated two wakefield monitors that allow for a very high precision steering of the beam to the structure axis. At present we are also studying the possibility to have a remote mechanical alignment of the structure in the transverse plane in ±0.5 mm range. One important feature of this structure design, which is also important from the beam dynamics point of view, is the coupler design which based on SLAC mode launcher design [10]. The purpose of this coupler type is to convert the rectangular waveguide TE_{10} mode into the circular TM_{01} mode. The main objective of this kind of couplers is to substantially reduce the surface field at the edges of the coupling irises to avoid RF breakdown. The input and output mode launchers and adjacent matching cells are mainly optimized from the RF point of view in a way to be matched with the regular cavities of the structure. This optimization necessitates that the RF operating mode of the mode launcher works in a TM_{012} mode which means that the electron bunch will travel along both of the mode launchers out of synchronization with the RF wave.

* mostafa.ashmawy@lycos.com

BEAM DYNAMICS IN INPUT AND OUTPUT MODE LAUNCHERS.

For simplicity, we will consider a short structure consisting of the input mode launcher, followed by its matching cell and 5 regular cells, then the output mode launcher preceded by its matching cell, see Fig. 2 (up). The electric field along the axis of this short structure from 0 to 2π at 5 degree step (thin lines) is shown in Fig. 2 (down). As shown, the particles should be injected in a certain phase in order to bring the particles in synchronization with the maximum negative E-field envelope along the first matching cell and the following 5 regular cells; this in turn force the particles to be out of synchronization with E-field along the input mode launcher and output mode launcher and its matching cell as indicated by blue thick line in Fig. 2 (down). The operating TM_{012} mode of the mode launcher is another reason that made the particles travel asynchronously with the E-filed along the mode launchers. In order to explore the influence of the non-synchronous fields on the beam quality we will remove 6 cells from the short accelerating structure and the original beam will be tracked along both the input and output mode launchers back to back leaving only one matching cell in between. Fig. 3 (left) represents relative energy spread and the projected rms normalized beam emittance in transverse plane in x and y directions. As noticed, the rms beam emittance is almost preserved, while the correlated energy spread is reduced due to the X-band RF curvature. However, the net energy gain of the electron beam along the mode launchers and one matching cell is positive (≈ 0.06 MeV) as shown in Fig. 3 (right) although the beam is basically injected in deceleration phase with respect to the regular cells. This means that the length of both mode launchers and one matching cell (≈ 10 cm) are useless from the acceleration/deceleration point of view; this is the only disadvantage of the mode launchers observed so far.

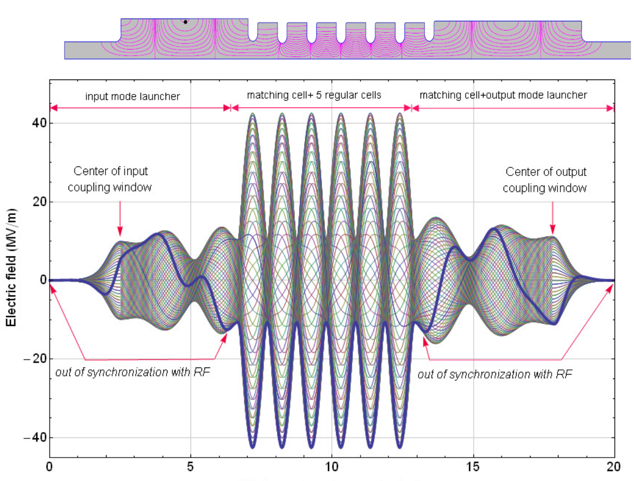

Figure 2: Up: 6 cells in between the input and the output mode launchers. Down: Electric field along the structure at 5° step (thin lines) and the electric field acting on reference particle (thick line).

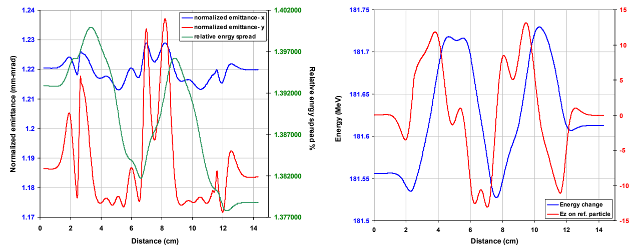

Figure 3: Beam behaviour along the input and out put mode launchers and matching cell in between; the projected rms normalized beam emittance in transverse plane and relative energy spread (left); kinetic energy change and the electric field acting on the reference particle (right).

BEAM DYNAMICS FROM X-BAND TO SPREADER

The designed electron beam parameters at the entrance of the X-band structure (see Fig. 4 - up) has been tracked along the X-band structure. The target is to reduce the electron beam by 20 MeV, based on calculation mentioned in the first section, and to keep the beam emittance preserved provided that the relative energy spread does not exceed 2% without change in the beam current profile.

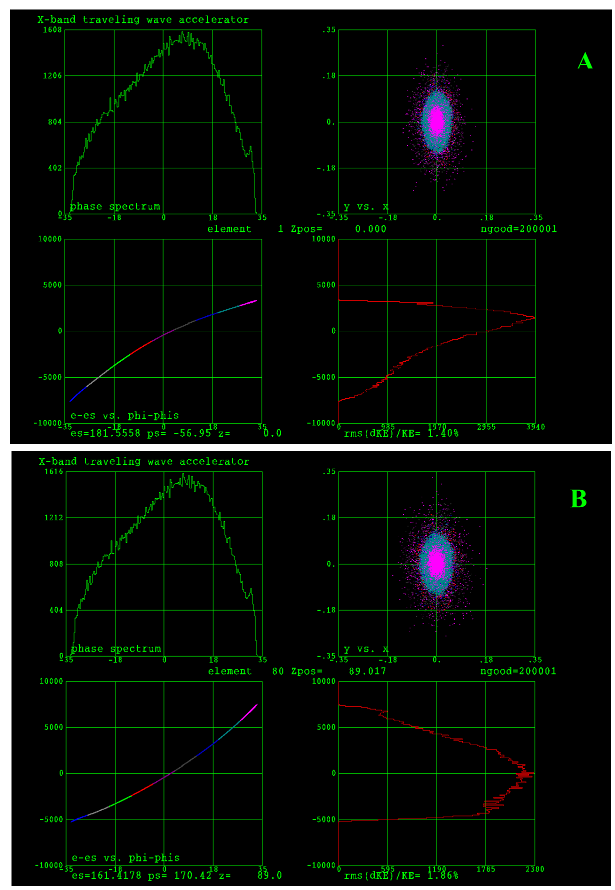

Figure 4: Beam parameters at the entrance (A) and exit (B) of X-band linearizer: longitudinal profile (up-left), transverse profile (up-right), energy-phase spectrum (down-left) and energy distribution (down-right)

Fig. 4 (down) shows the electron beam parameters at the end of the X-band linearizer. Fig. 5 shows the rms projected and sliced normalized emittance at the start and end of the X-band structure in the transverse plane. Each slice is represented by different colour segment shown in energy-phase spectrum in Fig. 4. It is clearly shown that all of the designed beam parameters are well maintained at the X-band structure. After the X-band linearizer, the beam has been tracked up to the end of Linac4 (see Fig.1) using *elegant* code to investigate the flatness of the beam current just before the undulator entrance. The target at the undulator entrance is to achieve mono-energetic (rms relative energy spread less than 0.1%) bunch of uniform charge distribution. Fig.6 shows the results of elegant simulation at the end of the spreader, as shown all designed beam parameters at the undulator entrance are fulfilled which entails successful FEL process.

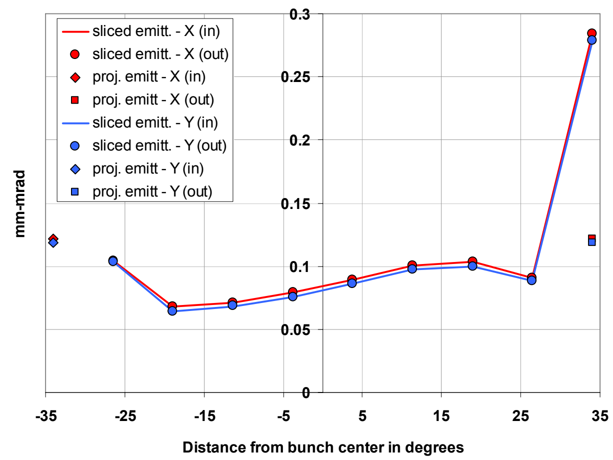

Figure 5: rms transverse normalized projected (lines) and sliced (circles) emittance of the electron beam at entrance (triangles) and exit (squares) of the X-band linearizer in the x (red) and y (blue) directions.

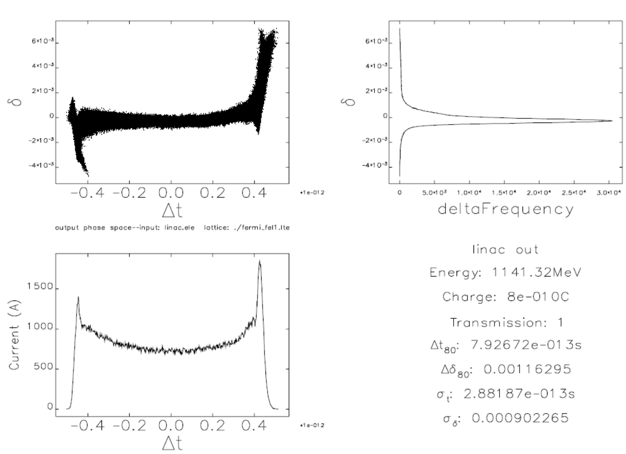

Figure 6: Beam output parameter: the phase-energy spectrum (up-left), relative energy spread (up-right) and the beam current (down-left) at the undulator entrance.

CONCLUSION

Transverse and longitudinal beam dynamics along PSI-CERN-ELETTRA X-band structure is presented. The simulations showed that for the desired synchronization of the electron bunch with the RF wave along the regular cells, the electron bunch should travel along the input mode launcher and output mode launcher and its matching cell asynchronously with the RF wave this in turn leads to almost zero energy gain in this part of the structure. Nevertheless, this asynchronous behaviour does not affect the designed beam parameters at the end of the X-band structure as verified by Tstep code. the results are confirmed up to the end of linac 4 with *elegant* code. The simulation also indicated that the X-band structure will have a great performance in linearizing the longitudinal phase space of the electron bunch at the undulator entrance of FERMI@ELETTRA FEL.

ACKNOLEDGEMENT

The authors undertook this work with the support of the ICTP programme for Training and Research in Italian Laboratories, Trieste, Italy

REFERENCES

[1] M. Dehler, J.-Y. Raguin, A. Citterio, A. Falone, W. Wuensch, G. Riddone, A. Grudiev, R. Zennaro, "X-band rf structure with integrated alignment monitors", Phys. Rev. ST Accel. Beams, 12, 062001 (2009).

[2] TStep, "an electron linac design code", by Lloyd M. Young, LMY TECHNOLOGY

[3] M. Borland, "*elegant*"- A flexible SDDS-compliant code for accelerator simulations, APS Tech. Note LS-207, (2000).

[4] FERMI@Elettra Conceptual Design Report

[5] D. Dowell, T. Hayward and A. Vetter, "Magnetic Pulse Compression Using a Third Harmonic Linearizer", Proceedings of the 1995 Particle Accelerator Conference, Dallas, TX, (1995).

[6] K. Floettmann, P. Piot, *The TESLA X-FEL Injector*, Proceedings of the Particle Accelerator Conference, Chicago, IL, (2001)

[7] P. Emma, "X-Band RF Harmonic Compensation for Linear Bunch Compression in the LCLS" SLAC-TN-05-004 LCLS-TN-01-, (2001).

[8] A. Bacci, M. Migliorati, L. Palumbo and B. Spataro, "an X-band structure for longitudinal emeittance correction at SPARC" SPARC-RF-03/001 LNF-03/008(R) (2003).

[9] G. D'Auria et al. "The X-band system for the FERMI@ELETTRA FEL project" this proceeding.

[10] C. Nantista, S. Tantawi and V. Dolgashev, "low-field accelerator structure coupler and design techniques" Phys. Rev. ST Accel. Beams, 7, 072001 (2004)