Lecture 10

Beam Diagnostics: Measuring the Longitudinal Phase Space Without a Transverse Cavity

• Description of the Experiment for measuring both the longitudinal and slice emittances
• Analysis technique of the data yields the longitudinal beam matrix and indicates a large correlated energy chirp out of the gun.
• A comparison of the measurements with simulations show the correlation comes from $0-\pi$ mode beating excited by the RF pulse.
• The technique of measuring the slice emittance by chirping the bunch energy combined with a quadrupole scan is described.
GTF Longitudinal Phase Space Measurements

Longitudinal phase space
Determined at entrance to linac

Gun & Solenoid

Vary Linac Phase

Linac

Quad1

Quad2

Phosphor

OTR

100 micron thick Yag

Spectrometer

YAG1

YAG2

Energy Spectrometer

Measure Energy Spectrum

Spectrometer Screen

GTF Diagnostics and Transport
**Analysis of Energy Spread vs. Linac Phase gives Longitudinal rms Parameters**

Symmetric longitudinal beam matrix:

\[
\tau = \begin{pmatrix}
\tau_{11} & \tau_{12} \\
\tau_{12} & \tau_{22}
\end{pmatrix} ; \quad \tau_{11} = \sigma^2_{t,\phi} ; \quad \tau_{22} = \sigma^2_E
\]

\[
\tau(\text{spectrometer}) = R_{\text{acc}} \tau(\text{gun + drift}) R_{\text{acc}}^T
\]

\[
R_{\text{acc}} = \begin{pmatrix}
1 & 0 \\
-E_{\text{linac}} \sin \phi_{\text{linac}} & 1
\end{pmatrix}
\]

\[
\tau(\text{spectrometer}) = \begin{pmatrix}
\tau_{11} \\
\tau_{12} - \tau_{11} E_{\text{linac}} \sin \phi_{\text{linac}} \\
\tau_{12} - \tau_{11} E_{\text{linac}} \sin \phi_{\text{linac}} (2\tau_{12} - \tau_{11} E_{\text{linac}} \sin \phi_{\text{linac}})
\end{pmatrix}
\]

\[
\sigma_E(\text{spectrometer}) = \tau_{22} - E_{\text{linac}} \sin \phi_{\text{linac}} (2\tau_{12} - \tau_{11} E_{\text{linac}} \sin \phi_{\text{linac}})
\]

Find \(\tau_{11}, \tau_{12}, \tau_{22}\) by fitting energy spread vs. linac phase

Offset of Minimum Energy Spread from Maximum Energy Gain gives Chirp at Linac Entrance

Energy Chirp, MeV/degRF:

\[
\frac{\Delta E}{\Delta \phi} \bigg|_{\text{linac entrance}} = E_{\text{linac}} \sin \phi_{\text{linac}}
\]

Bunch energy vs. linac phase

Bunch energy spread vs. linac phase

SLAC Gun Test Facility data
Result of Longitudinal Emittance Measurement

High Brightness Electron Injectors for Light Sources – June 14-18, 2010
Gun probe signals show $0-\pi$ mode beating which can explain large correlated energy from gun
RMS energy spread at 35 MeV vs. linac phase
Linac puts energy-chirp onto electron bunch

Quads varied to scan beam sizes at spectrometer screen

Spectrometer used in beam-based transport measurements

Measure energy-dispersed images vs. quad current. Energy => Time
Transverse size => Emittance

High Brightness ElectronInjectors for Light Sources – June 14-18, 2010
Chirped Bunch at 15 pC
For Two Quadrupole Strengths

High Brightness Electron Injectors for Light Sources – June 14-18, 2010
15 pC slice fits, l-solenoid = 104 amps
Conversion from Energy to Time Comes From Longitudinal Emittance Measurements

High Brightness Electron Injectors for Light Sources – June 14-18, 2010
Slice and projected emittances determined for 300 pC bunch charge. The slice time width is 330 fs. These data show an inverse relation between the best slice and projected emittances when optimizing with the solenoid. Therefore projected emittance measurements alone cannot give an optimized beam.

Lecture 10
Beam Diagnostics

• Described technique for measuring the longitudinal phase space and slice emittance without a transverse cavity.