Beam Stability and Requirements on Technical Components

LEReC Review

August 12, 2013

Basic Parameters

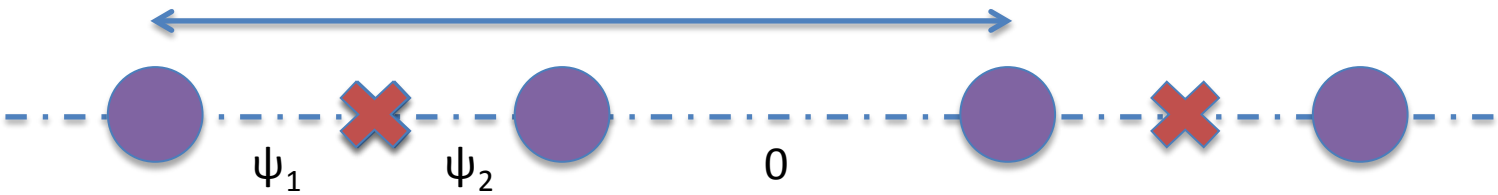
- Positioning of the electron beam should provide an overlap and r.m.s. angular deviation between electron and ion beams should be defined mostly by electron beam emittance (90-150 microradians)
- Electron beam: 0.5-1 nC per bunch, $\sigma E/E<5\times10^{-4}$, bunch length 0.5-1 ns, normalized emittance of 2.5 μm
- Relative energy mismatch should be below 10^{-4}
- Time and amplitude jitter of the electron beam can cause ion beam heating due to the varying tune shift (see G. Wang)

Contributing Factors

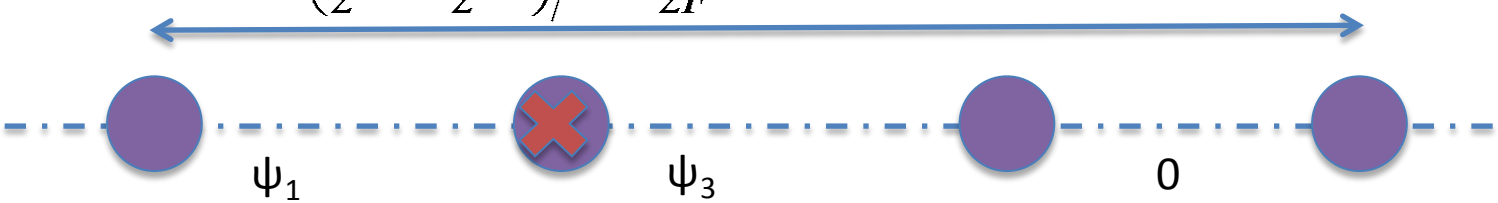
- Laser intensity variations
- Laser jitter
- Electron beam emittance
- Power supplies ripple and drifts
- Accuracy of mechanical alignment of solenoids
- Vibrations and drifts of solenoids
- BPM noise (for BBA and orbit feedback)

Solenoids Misalignment

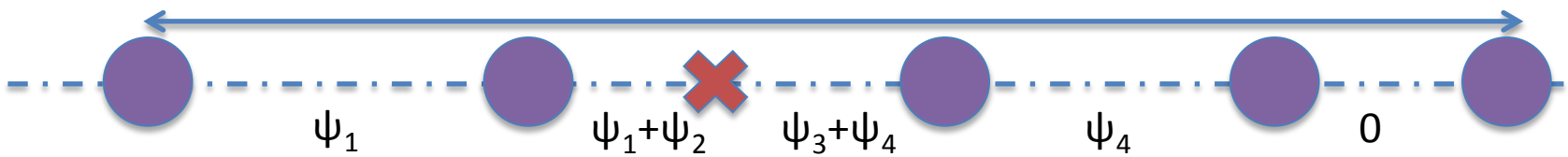
With set of horizontal and vertical trims per each quadrupole contribution is small. Trims correct the kick in each solenoid and r.m.s. beam deviation is defined by distance between solenoid and trim. Focal length of the solenoids in the cooling section is around 30 meters, hence 1 mm offset we can reach about 1 nanoradians r.m.s. angular deviation, even with two trims per cooling section.



$$\bar{\psi}^2 = \left(\frac{1}{2}\psi_1^2 + \frac{1}{2}\psi_2^2\right)\Big/ 2 = \frac{\delta^2}{2F^2}$$



$$\bar{\psi}^2 = \left(\psi_1^2 + \psi_3^2\right)\Big/ 3 = \frac{2\delta^2}{3F^2}$$



$$\bar{\psi}^2 = \left(\psi_1^2 + \frac{1}{2}(\psi_1+\psi_2)^2 + \frac{1}{2}(\psi_3+\psi_4)^2 + \psi_4^2\right)\Big/ 4 = \frac{\delta^2}{F^2}$$

Calculations use assumption $L_{mag} << F$

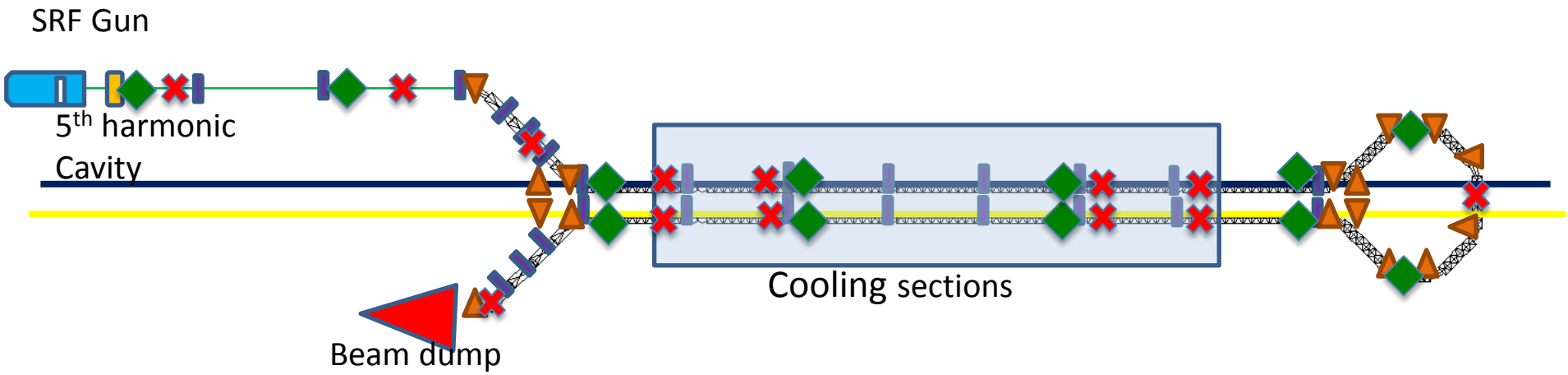
Beam Position Monitors

The position od the electron beam can be monitored with Libera Single Pass receiver. The error for a single pass of 1 nC bunch is 10 microns (angular resolution of 1.0 microradians with base of 10 meters). Averaging over multiple passes and increasing number of bunches reduces the error even more. Setting the input band-pass filter frequency high (500 MHz) allows to suppress the signal induced by the ion bunches.

Ion beam can be monitored by the Libera Hadron units connected to the same pick-up electrodes. These unit will require lower band-pass filter frequency (10-100 MHz). Effect of the electron beam can subtracted from the data from electron BPM receivers. Calibration can be done using switching on and off electron beam.

To establish and upkeep the angular trajectory two BPMs per cooling straight is sufficient. For redundancy we will put two pairs of BPMs two in the start of the cooling section and two at the end. Additional BPMs will be installed in the beam transport section. One of the in center of the turning arc to monitor the electron beam energy. The 10 microns noise translates into the 3×10^{-6} error in energy monitoring for 3 m dispersion.

LEReC Schematic Layout



Beam position monitors

Orbit correctors

Number of BPMs and correctors in the cooling sections is limited to provide maximal space for magnetic field free region.

BBA can be done with single pulse operation with 100% solenoid modulation and observing beam displacement at the downstream BPM. One microradian angular resolution (10 microns noise) gives 30 microns error in magnet center definition.

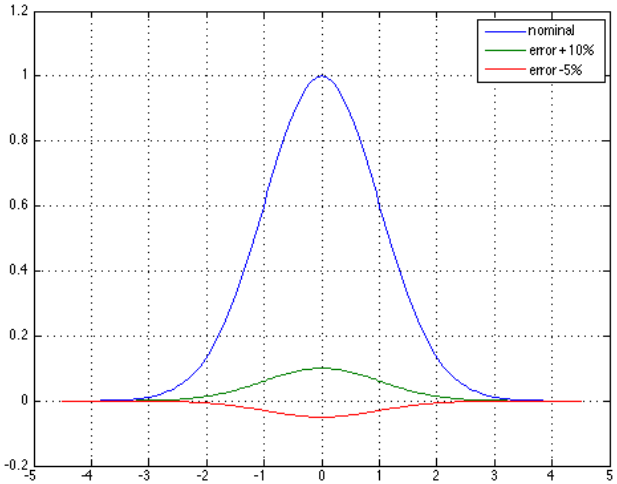
Power Supplies Drifts and Ripple

Lattice design and choice of the common power supply for the dipoles allows to reduce requirements for power supplies. The dipoles can be made identical within 10^{-3}. Ripples and drifts are within 0.1% of full scale for usual for of the shelf power supplies (ATE-DMG by Kepco 1 kW has 0.03% r.m.s. ripple and noise, 0.3% peak-to-peak). So beam will affected by less than 1 microradian motion due to the ripples in dipole power supply. The edge focusing by the dipoles has focal length is about 1 meter. Limiting deviation of the orbit from the median plane to 1 mm provides for the kicks less then 1 microradian.

We need to limit the beam deviation from the magnetic center of solenoid to 1 mm. In this case 0.1% ripple in the solenoid current will give angular kick of 1 microradian for solenoid with maximal focusing strength (F=1 m). I also limits the required trim strength to 1 mrad and kick to the beam with 0.1% power supply ripples will be on the order of 1 microradians.

Magnets vibration in RHIC is around 1 micron – much smaller than alignment tolerances. Should not be a problem. Solenoids in cooling section have F=30 meters.

Jitter Requirements

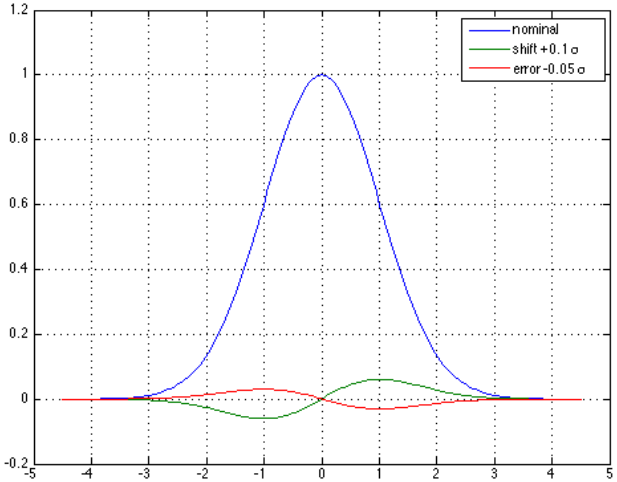


For amplitude jitter the limit is 7% when the growth of the beam emittance due to the modulation of the betatron frequency is equal to 1000 seconds. Such shot-to-shot charge variations can be easily monitored with beam charge monitor by Bergoz, which fas dynamic range over 800.

$$\int (\delta I)^2 dt = \int_{-\infty}^{\infty} \delta_A^2 I_{peak}^2 \exp\left(-\frac{t^2}{\sigma_e^2}\right) dt = \sqrt{\pi}\sigma_e \delta_A^2 I_{peak}^2$$

With time jitter it also possible to describe electron beam current as sum of nominal and error currents

$$\int (\delta I)^2 dt = \int_{-\infty}^{\infty} \frac{\delta_T^2 I_{peak}^2 t^2}{\sigma_e^4} \exp\left(-\frac{t^2}{\sigma_e^2}\right) dt = \sqrt{\pi}\sigma_e \left(\frac{\delta_T}{2\sigma_e}\right)^2 I_{peak}^2$$



Time jitter provides the same level of current fluctuations as amplitude jitter if

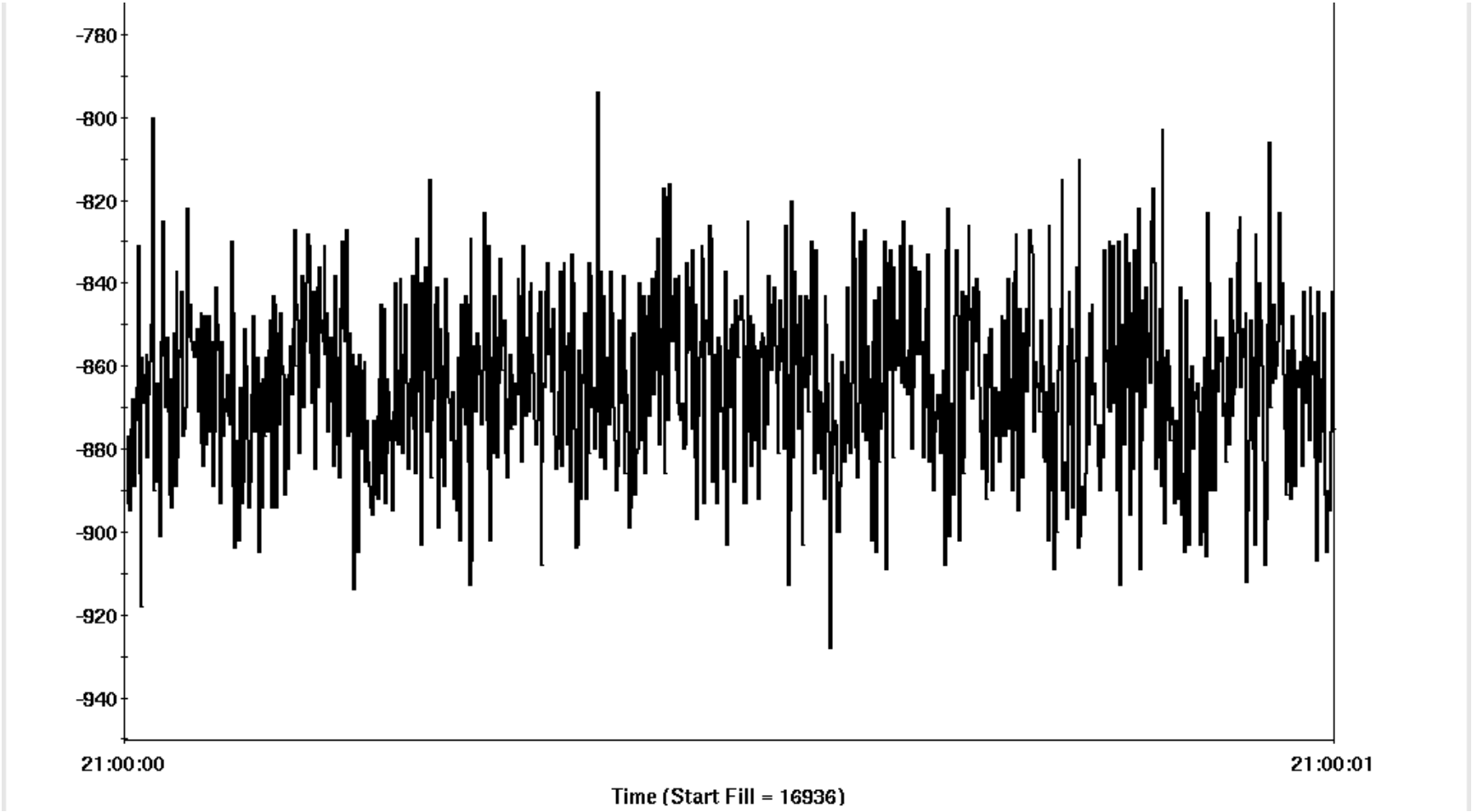
$$\delta_T = 2\delta_A \sigma_e$$

For 700 ps electron bunch length we have 100 ps jitter requirement . We have measured ion beam jitter less than 25 ps.

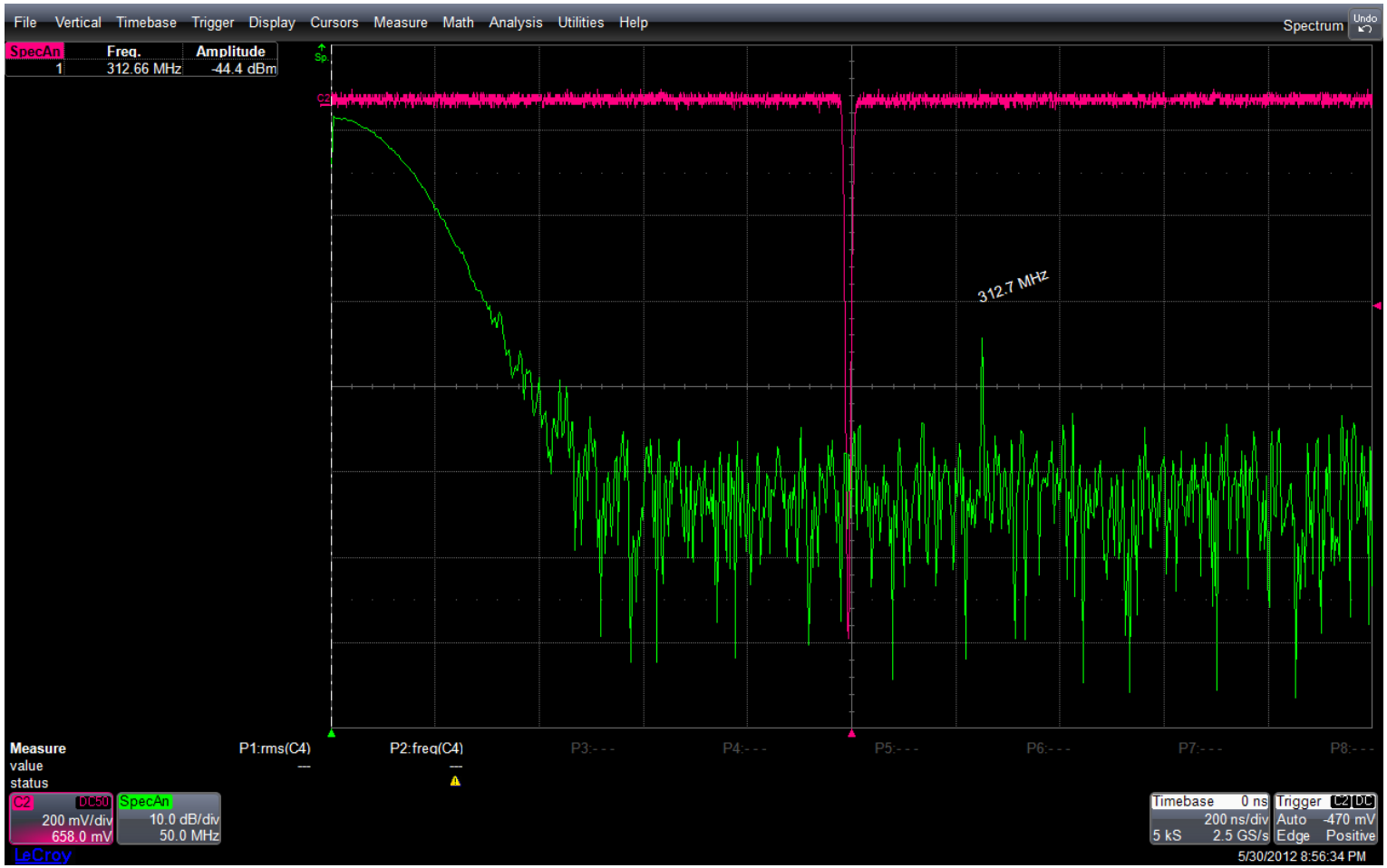
Summary

- The angular deviation of ion and electron beam is defined mostly by the electron beam emittance
- The required tolerances on the noise of beam position monitors is moderate and is achievable by existing commercial units
- The requirements on the power supply ripple and noise are moderate due to the proper choice of the lattice
- Requirements on electron beam jitter can be easily met and existing diagnostics has sufficient characteristics

Orbit Stability



Jitter Measurement

Period 1.0657398 µs corresponding to 78.192945 kHz. FWHM is about 120 ps, r.m.s. is 50 ps

Beam Spectrum (500 MHz span, 150 kV, 28 MHz)