

# Week 2

## Problem Set 5 — due Tuesday, 2018 January 23, 9:00 a.m.

- Chromatic Light Source.** The following measurements are performed in an electron synchrotron operating at an energy of 9 GeV. The RF frequency (nominally 390 MHz) is increased by 3 kHz from its original value, and the horizontal tune is measured to be 20.428. Next, the RF frequency is decreased from its original value by 3 kHz and this time the tune is found to be 20.442.
  - What relative change in momentum,  $\Delta p/p$ , did the beam experience between these two measurements? Note that  $1/\gamma_t^2 = 3 \times 10^{-3}$  in this ring.
  - If the horizontal dispersion function has a value of 0.6 m at a particular beam position monitor (BPM), what relative horizontal displacement would be detected at this location between these two measurements?
  - At what value of chromaticity is the accelerator operating?
- Gradient Errors.** An accelerator has 100 quadrupole magnets powered in series, so that each has the same magnetic field. The focal length of the quadrupoles is 20 m and the amplitude functions at their locations have values  $\beta_x = 80$  m and  $\beta_y = 20$  m.
  - If the magnetic gradient of all the quadrupoles is increased by 0.2%, what tune shift would this generate in each degree of freedom (horizontal and vertical)?
  - If, instead, each magnet is independently powered, and the setting of each power supply is accurate to 0.5%, estimate the accuracy to which the horizontal tune can be adjusted.
- Beam injection.** A beam made of 1 million protons with  $p_0 = 3.9$  GeV/ $c$  and uniform momentum spread within the range  $-0.01 < \delta p/p < 0.01$  is intended to be injected into a storage ring with constant dispersion function  $D_x = 8.3$  m, and bending radius  $\rho = 7.112$  m. The horizontal betatron phase space (in coordinates  $x, \beta_x x' + \alpha_x x$ ) of the incoming beam is initially filled uniformly out to a maximum radius of 10 cm.
  - If the beam pipe inside the storage ring has a horizontal aperture of 4.5 cm, what is the range of momentum offsets  $\Delta p/p$  that can be sustained within the ring? Ignore vertical losses.
  - After many, many turns, estimate the percentage of the injected proton beam that will be lost due to collimation with the beam pipe.