1. Holzer, B.J. “Introduction to Particle Accelerators and their Limitations” May 2017. CERN. 10.5170/CERN-2016-001.29

Summary:

This paper describes the limitations of particle accelerators while explaining some of the physics concepts behind how these accelerators work. One such physical limit that is relevant to electricity and magnetism is an accelerator's magnetic guide field. The paper briefly describes how dipole magnets bend the charged particles to make them stay in orbit around the accelerator. The paper focuses more on the quadrupole magnets that focus the beam, and keep the particles closer together.

The quadrupole magnets exert a linear restoring force on the particles. Due to the orientation of the magnetic field lines and Maxwell’s' equations, a dipole magnet will focus a beam of particles in the horizontal plane and defocus the beam in the vertical plane, or vice versa. To compensate for this, accelerator rings have a series of alternating focusing and defocusing quadruple magnets that have a net focusing effect on the beam. See Figure 14 in the paper for a diagram of the magnetic fields of a quadruple magnet.

2. E.D. Courant, M.S. Livingston, and H.S. Snyder. 1952. "The Strong Focusing Synchrotron - A New High Energy Accelerator." The Physical Review, 88: 1190-1196.

Summary:

This paper goes into more details about strong focusing. In synchrotrons (and other accelerators) some of the particles will deviate from their design trajectories due to the energy spread in the injected beam, scattering by residual gas, magnetic inhomogeneities, or frequency errors. These deviations are oscillatory and the paper mathematically describes the amplitudes, frequencies, and relative stabilities of these oscillations. However, I am more interested in focusing (no pun intended) on the corrections for these oscillations, one of which is strong focusing.

Strong focusing uses quadrupole magnets of alternating gradients to focus particle beams kind of like a series of lenses. A quadrupole magnet used in a synchrotron has a doubly-divergent magnetic field with uniform and equal values of dBz/dy and dBy/dz with the center of the magnet on the x axis. The pole faces of the magnet are shaped like rectangular hyperbolas. In a strong focusing lens, there would be two of these magnets separated by some length and rotated 90 degrees relative to each other.