RF Approach to HEDP

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RF Acceleration in Front End

- Parameters
  - 0.1 to 1.0 microcoulomb singly-charged Ne
  - 1 MV initial acceleration, beta ~ 0.01
  - 200 MHz, 100 bunches, 6×10^{10} particles/bunch
  - Solenoid focusing, several Tesla
  - Helical accelerating structure

Helix Geometry and Field Fall-off

Sheath radius 6 cm to accommodate beam

v/c = 0.01 => winding pitch 0.57 degrees
Turn-turn spacing 0.38 cm

Longitudinal Field is $E_z \sim I_0(kr)$

where $$k = \sqrt{\left(\frac{\pi}{L}\right)^2 - \left(\frac{\omega}{c}\right)^2} \approx \frac{2\pi}{\beta\lambda}$$

L here is the periodicity of the field, k ~ 4.2/cm
For a = 6 cm, $I_0(0) = 1$, $I_0(ka) \sim 6\text{x}10^9$

Therefore, no E_z on axis

For 20 MHz, $I_0(ka) = 3.3$; 2 MHz, $I_0(ka) = 1.02$

Longitudinal Fields in the Bunch

Leading term: (less valid for $z_b < a$)

$$E_z \approx \frac{gc}{4\pi\epsilon_0 c}\frac{2\rho}{z_b}, \quad \rho = \frac{Q_{bunch}}{z_b}, \quad g = 1 + 2\ln\left(\frac{b}{a}\right)$$

where beta lambda = 1.5 cm, z_b ~ .25 cm for 60 degree bunch

For 10^{-8} coulomb in a single bunch (100 bunches) and
a geometry factor g ~ 2,

$$E_z = 58 \text{ MV/m}$$

Alternative Calculation of Self-Fields

Potential well of d.c. beam

$$V_{well} = \frac{30\, I}{\beta}, \quad E_z \approx \frac{V_{well}}{z_b/2}$$

This gives a value of 28 MV/m.

On inspection, this is the same as the previous formula for E_z, except the geometry factor g is omitted.

Bunching Process Itself

- Beam must be bunched before it can be accelerated
- Kick buncher? Adiabatic buncer? What?
- Even if self-fields not an issue, both will produce at least a 1% momentum spread
- Kick buncher acceptance probably < 50%
- Adiabatic bunching takes a long time (space, distance)
- But self-fields will prevent adequate bunching anyway

Check the Focusing

Model Ne^{+1}, v/c = 0.01 d.c.beam in a solenoidal field
Match <=> minimize envelope oscillations
KV approximation => no stay-clear
Paraxial equation (accelerating terms omitted)

$$r'' = \left(\frac{e}{m_0 c^2}\right)\left[\frac{-r}{4}\left(\frac{e}{m_0 c^2}\right)\frac{1}{\gamma}(Bc)^2 + \frac{I}{2\pi\epsilon_0}\frac{1}{\beta^2\gamma}\frac{1}{r}\right] + \frac{e_{norm}^2}{\beta^2\gamma^2 r^3}$$

DC current (amps)	Solenoidal Field (T)	Envelope (cm)
2	4	2.5
10	4	5.7
2	6	1.7
10	6	3.9
10	8	2.7

SC Solenoid required, but actual helix radius will need to be even larger than 6 cm, or field larger than 4 T.

Lower the Frequency?

- Lowering the RF frequency will lower the gradient
- Lower limit is a single bunch, with a ramped field
  - This is Dick Brigg's solution already
- The non-RF, single-bunch solution looks much more favorable than trying to make RF work.
- Even so, check the $I_0(kr)$ term over the spectral components of a ramped pulse