Examination on LINAC course – JUAS 2017

Jean-Baptiste Lallement – Veliko Dimov – Jimmy Garland - CERN – 8/02/2017

All needed formulas and data are given in the annex.

I. One to two sentences answers. (6 points)

1) What is the main advantage of RF Linacs compared to static Linacs?
2) What is the transit time factor?
3) Explain the principle of longitudinal focusing of non-relativistic particles.
4) We have two similar FD focusing channels with 70° and 50° phase advance per period ($FD_{70°}$ and $FD_{50°}$). In which one the matched beam envelope is the largest? For which channel are the quadrupoles gradients the highest? Assuming no RF defocusing and no space charge, what is the ratio between the quadrupoles gradients?

II. Pillbox cavity. (5 points)

1) Is a 200 MHz, 100 mm long ideal pillbox cavity adapted to accelerate 1 MeV protons? (2 points)
2) Is this cavity better adapted to lower or higher energy protons? (1 point)
3) What is the maximum energy gain of a 1 MeV proton traversing a 200 MHz ideal pillbox of length 30 mm with an average field equal to 1 Kilpatrick? (assuming the average field on axis is equal to the maximum field on the surface for an ideal pillbox). (2 points)

III. DTL. (7 points)

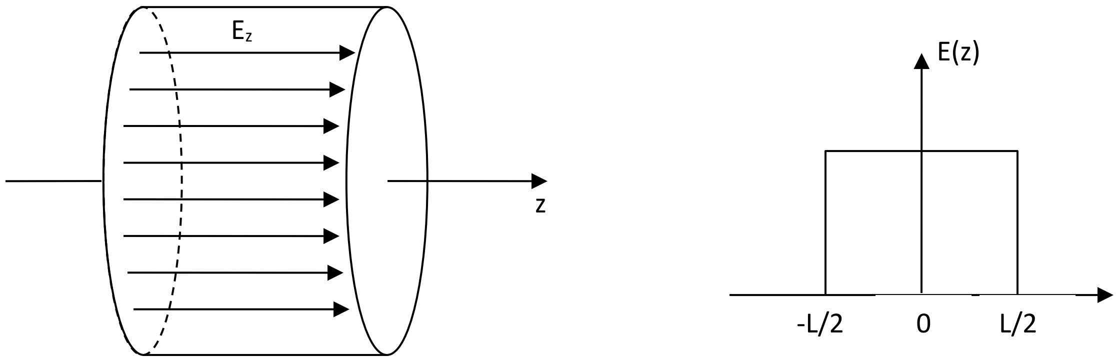
Consider a 350 MHz Drift Tube Linac with an FD focusing scheme accelerating 3 MeV protons.
The average field on axis E_0 is 3 MV/m, synchronous phase ϕ_s is -30° and transit time factor 0.8.
The quadrupoles are 50 mm long and their gradient is 100 T/m.
Assuming no change in particle velocity and no space charge:

1) What is the length of a focusing period? (1 point)
2) Calculate the zero current longitudinal phase advance per focusing period σ_{0l}. (2 points)
3) Calculate the zero current transverse phase advance per focusing period σ_{0t}. (3 points)
4) What is the ratio transverse to longitudinal phase advance $\frac{\sigma_{0t}}{\sigma_{0l}}$? What should we do to reduce this ratio, without changing the longitudinal parameters? (1 point)

IV. Acceptance. (2 points)

Suppose that we are modifying the design of an accelerating structure and that we want to increase the maximum energy acceptance by 25% by increasing the average electric field E_0. What should be the corresponding increase of E_0 in percent?

Annex: Useful formulas and data



TM$_{010}$ mode in a pillbox cavity

Square-wave electric field distribution

Fig. 1 *Pillbox cavity*

Proton mass: 938.27 MeV

Transit-time factor approximation for a square-wave electric field distribution: $T = \frac{\sin(\pi L / \beta\lambda)}{(\pi L / \beta\lambda)}$

Energy gain in a cavity: $\Delta W = qE_0 TL\cos\phi_s$

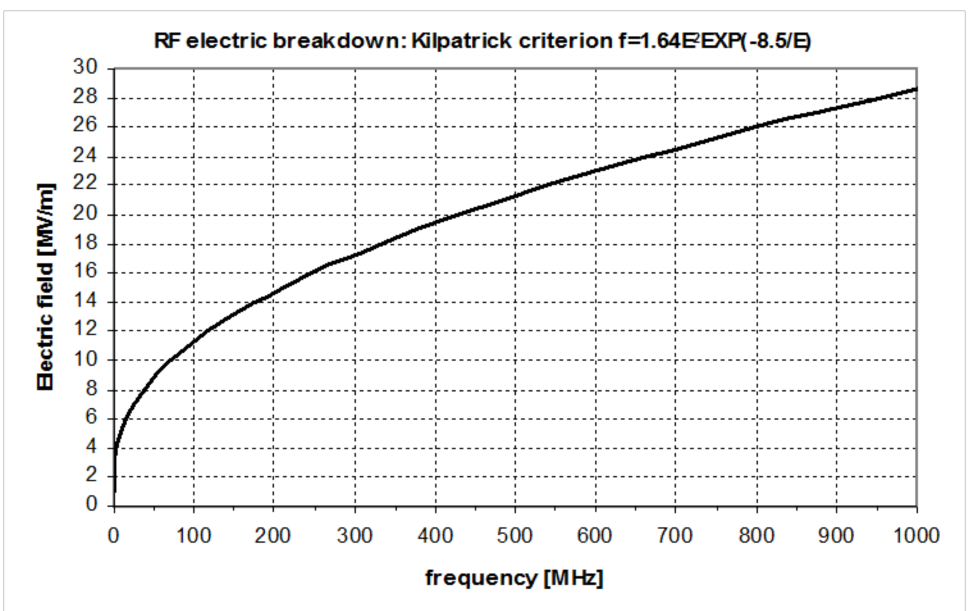
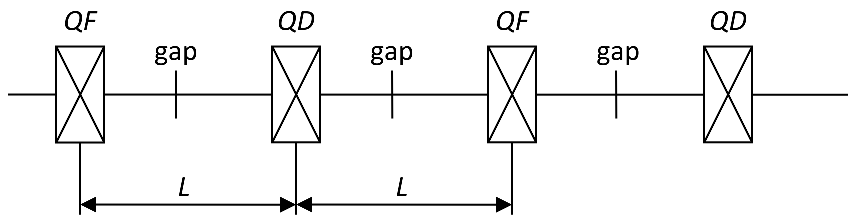


Fig. 2 *Kilpatrick limit for RF electric breakdown*

Transverse phase advance <u>per period</u> (FD lattice):

$$\sigma_{0t} \approx \sqrt{\left(\frac{qGl_q L}{m_0 c\gamma\beta}\right)^2 - \frac{\pi q E_0 T \sin(-\phi)(2L)^2}{m_0 c^2 \lambda (\beta\gamma)^3}}$$



FODO period P=2L

Longitudinal phase advance <u>per unit length</u>: $k_{0l} = \sqrt{\frac{2\pi q E_0 T \sin(-\phi_s)}{m_0 c^2 \beta_s^3 \gamma_s^3 \lambda}}$

Longitudinal separatrix equation:

$$\frac{\omega}{2m_0 c^3 \beta_s^3 \gamma_s^3}\Delta W^2 + qE_0 T[\sin(\phi_s + \Delta\phi) + \sin\phi_s - (2\phi_s + \Delta\phi)\cos\phi_s] = 0$$

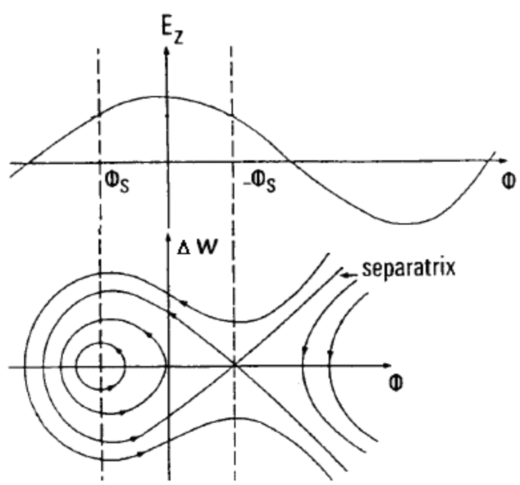


Fig. 3 *Separatrix in the longitudinal phase space.*