PROGRAM FOR THE GENERATION OF HIGH CURRENT RFQ

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Abstract

In general design of the linear accelerators, the beam dynamics parameters are calculated from data describing the accelerator structure. In this approach, the desired phase advances (beam dynamics parameters) are obtained after several iterations of structure parameters. A program has been written for the generation of RFQ Linac, which is based on choosing the zero current transverse and longitudinal phase advances. Given the zero current transverse and longitudinal phase advances, the structure parameters are calculated using the analytical formulae. In this paper, we discuss the design of the high current RFQ using this procedure and compare it with the ones obtained from the standard codes.

INTRODUCTION

The renewed interest in Acccleerator Driven Systems (ADS) has spurred tremendous interest in developing high intensity proton accelerators, and set challenging demands in terms of delivering high current (~ tens of mA) and high energy ($\geq$1 GeV) required for the spallation process. In Indian context, ADS will be used for the utilization of thorium resources for the energy production. In view of the importance of ADS, a project to design and build a 20 MeV, 30 mA CW proton accelerator (LEHIPA) as an injector to 1 GeV Linac has been initiated.

The LEHIPA [1] mainly consists of a 50 keV ECR ion source, Low Energy Beam Transport (LEBT) line, 3 MeV Radio Frequency Quadrupole (RFQ) accelerator, Medium Energy Beam Transport (MEBT) line and a 20 MeV Drift tube Linac (DTL).

The Linac for the ADS system requires extremely low beam loss in order to allow hands-on maintenance. It has also been studied that if the beam is not in thermal equilibrium, the equipartitioning process caused by the strong coupling between the transverse and longitudinal motions can lead to emittance growth [2] and halo formation [3,4]. Hence we have studied ability of the RFQ to prepare an equipartitioned beam. The choice of the phase advances per focusing period (with, without space charge) of the transverse (σ_t,σ_{0t}) and longitudinal (σ_l,σ_{0l}) oscillations are crucial for the design of high current accelerators. These parameters not only determine the motion stability but also the emittance growths and the halo formation which can produce undesirable beam losses in high current accelerators. The zero current phase advance parameters (σ_{0t} and σ_{0l}) determine the structure parameters. A program has been written for the generation of RFQ by choosing the phase advances at the end of the gentle buncher.

DESIGN STRATEGY

An equipartitioned beam has equal transverse and longitudinal temperatures,T_l=T_t. Theoretically, for a matched bunch in a smooth-focusing system, the temperatures can be related to the rms beam widths and normalized rms emittances [5].

$$\frac{T_l}{T_t} = \frac{\varepsilon_{\ln}^2}{\varepsilon_{tn}^2} \cdot \frac{a^2}{(\gamma b)^2} \tag{1}$$

Where ε_{tn}, ε_{ln} denotes the full (100%) normalized emittance of a uniform beam distribution, a and b corresponds to full beam radii in the transverse and longitudinal directions respectively, γ is the relativistic factor. From the envelope equations the full current phase advances (σ_t, σ_l) are given by

$$\sigma_t = \frac{\varepsilon_{tn}\lambda}{a^2\gamma} \tag{2}$$

$$\sigma_l = \frac{\varepsilon_{\ln}\lambda}{b^2\gamma^3} \tag{3}$$

where λ is the wavelength.

From the smooth approximation theory the phase advances with space charge for the uniformly ellipsoidal beam bunch are related to the external focusing forces in the form of:

$$\sigma_t^2 = \sigma_{0t}^2 - \frac{Q(1-ff)}{2a^2b} \tag{4}$$

$$\sigma_l^2 = \sigma_{0l}^2 - \frac{Qff}{a^2b} \tag{5}$$

where the bunch form factor *ff* is a function of γb/a [6] when 0.85$\leq$ γb/a$\leq$5 then *ff*=a/3γb, and $Q = \frac{3Z_0 qI\lambda^3}{4\pi m_0 c^2\gamma^3}$

with Z_0=377Ω

The Q parameter is then fixed by the choice of the beam current, I, the particle rest mass (m_oc^2), charge, and energy (W) and the operating frequency of the system.

For the equipartitioned beam the ratio of the transverse and longitudinal temperatures should be equal to one.

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From Eq. (1) we get $\frac{\varepsilon_{ln}}{\varepsilon_{tn}} = \frac{\gamma b}{a}$ and therefore by choosing the ratio of $\frac{\varepsilon_{ln}}{\varepsilon_{tn}}$ and from the equations (2)-(5) we can calculate the beam sizes as function of zero current phase advances. The zero current phase advances are chosen based on the following constraints in order to avoid envelope instabilities, resonances and space charge limits [7]

$\sigma_{0t}, \sigma_{0l} \le 90^0$

$\sigma_t/\sigma_l \neq$ n or 1/n (where n is integer)

σ_t/σ_{ot} , $\sigma_l/\sigma_{ol} > 0.4$

The next step is to determine the accelerator parameters which give the chosen phase advances and this choice should lead to a physically realizable design.

RFQ DESIGN

We have adopted the conventional philosophy, where RFQ is divided in to four sections namely RMS, Shaper, Gentle Buncher (GB) and accelerator. The parameters of the RFQ accelerator at the end of the GB section are calculated according to the basic formulae [8].

Accelerator section parameters

In accelerator design we kept the acceleration efficiency (A) and synchronous phase (φ_s) constant, so $\sigma_{0l} \propto \beta_s^{-1}$. In order to keep the ratio of the beam sizes constant to have a equipartitioned RFQ, σ_{0t} has been varied with βs. From the values of σ_{0t} and σ_{0l} the aperture (a) and modulation (m) are calculated as a function of energy.

Gentle Buncher parameters

The calculation of this section follows the K-T approach [9], where σ_{0l} and spatial length of the bunch Z_b are kept constant all along the GB section.

Shaper parameters

We have employed two different ways for the generation of shaper section.

a) The accelerator parameters modulation (m), aperture (a) and φ_s are varied linearly with the energy.

b) The focusing factor (B), φ_s, modulation (m) are varied linearly to the final values with the energy of the beam.

The shaper length has to be calculated in such a way that the energy gain in the shaper should be equal to the required energy gain at the end of the shaper.

NUMERICAL SIMULATIONS

The parameters of 3 MeV, 30 mA proton RFQ are generated by choosing the ratio $\frac{\varepsilon_{ln}}{\varepsilon_{tn}}$=1.3. The parameters are chosen in such a way to keep the peak surface field below 1.8 times kilpatrick limit all along the structure. In this design, the value of ρ/r_0=0.93 is kept constant along the RFQ, where ρ is the transverse radius of curvature and r_0 is average aperture radius. The parameters of the RFQ are shown in the Fig. 1 and enumerated in Table 1.

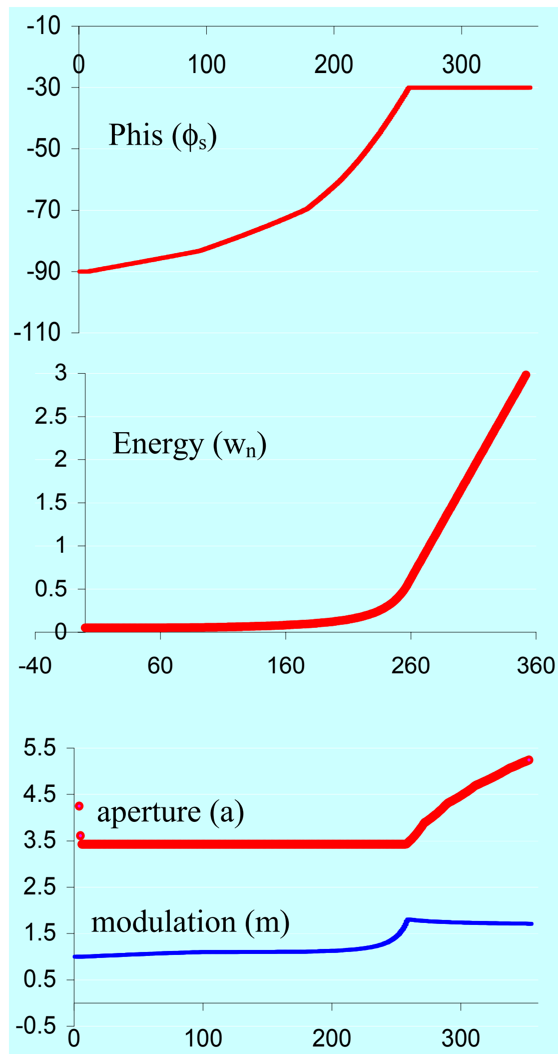

Figure 1: RFQ parameters (φ_s,W_n,m,a) vs cell number.

Numerical simulations of the beam dynamics have been performed with program LIDOS [10]. The variation of the longitudinal and transverse oscillation frequency along the length of the RFQ is shown in Fig 2. The initial particle distribution is waterbag in the transverse direction, with a normalized rms emittance of 0.02 π cm-mrad. It has been observed that the transverse emittance growth ($\varepsilon_{out}/\varepsilon_{in}$) is equal to one at the end of the RFQ. The variation of transverse emittance along the RFQ is shown in Fig 3. The transmission is more than 97%. The transverse zero current phase advance σ_{0t} is varied from 29.6^{o} at the beginning of the shaper to about 12.7^{o} at the end of the RFQ. The variation of the structure parameters by choosing the different ratios of $\frac{\varepsilon_{ln}}{\varepsilon_{tn}}$ has to be studied.

Table 1: Design parameters of RFQ

Parameter	Value
Input energy	50 keV
Output energy	3.0 MeV
Frequency	352.21 MHz
Intervane voltage	80.14 kV
Peak surface field	32.8 MV/m
Length	4.0 m
i/o transverse emittance	0.02/0.0204 cm-mrad
Output long. Emittance	0.037 cm-mrad

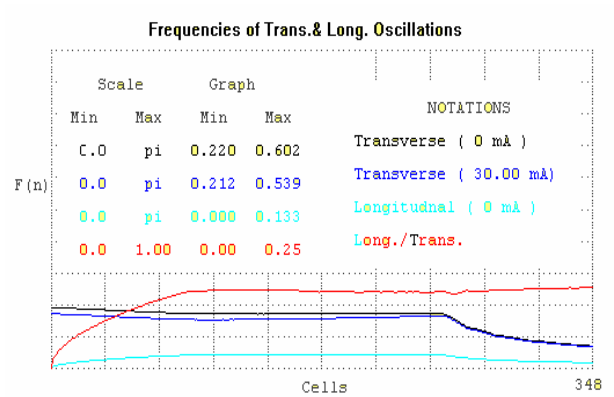

Figure 2: Logitudinal & Transverse oscillations vs cell number.

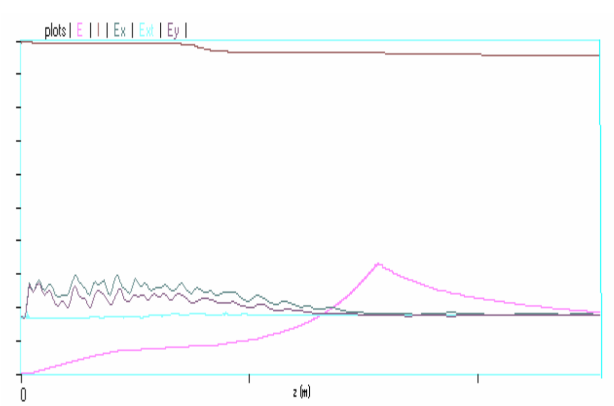

Figure 3: Transverse emittance vs z

CONCLUSIONS

The equipartitioning design procedure of RFQ linacs has been presented and it has been observed that this method can decrease the emittance growth. One of the main advantages with equipartitioned scheme is matching between the RFQ and DTL structures. Since the r_0 is increased in the accelerator section, the ρ has varied along the structure. So the fabrication of the vanes has to be done with ball & mill cutting tool.

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