EXTREME DENSITY CHARGE ELECTRON BUNCHES

S. S. Proskin, A. P. Kulago, I. S. Shchedrin, National Research Nuclear University – Moscow Engineering Physics Institute, Moscow, Russia

Abstract

This paper presents untraditional approach of obtaining the DLWG limited bunch charge (LBC). The maximum energy of accelerated bunch is considered. As a result the bremsstrahlung maximum dose rate evaluation is obtained.

INTRODUCTION

Conventional theory of linear accelerators is based on the power balance equation applied to the chosen accelerating structure: disk loaded waveguide (DLWG, working on travelling wave, or biperiodic decelerating structure).

Consider the different physically justified approaches to the issue of electron current loading in the accelerating structure. The idea of accelerating field definition forcing on accelerating electrons as an algebraic sum of power source accelerating field and total decelerating field emitting by accelerating electrons [1] in chosen accelerating structure is put within this approach basis. Detailed description is reviewed in [2]. According to this idea, the maximum dose rate of bremsstrahlung from target at the exit of linear accelerator is defined within this research.

MAXIMUM DOSE RATE OF BREMSSTRAHLUNG

Consider a specific data of obtaining charges density in DLWG in order to solve an issue of designing an electron linac with output energy of 4 MeV and a bunch charge of 50 pC to obtain powerful bremsstrahlung.

According to methodic described in [2] perform a calculation of bunch charges density with modern power sources made by Mitsubishi Electric Corporation. The company produces klystrons for high energy scientific accelerators, small and middle energy accelerators with application in medicine, for airports in landing control locators.

It is important to note that a choice of power source for different accelerators should be made focusing on a serial model and a production company that has enough orders. It is desirable that the power source has a demand in different sectors of economy, for instance, in aviation, in military sector, in national security.

Back to the charge density calculation and describing main equations from [2].

The field accelerating the bunch with charge q equals:

$$E = E_{S0}e^{-\alpha z} - qcR_S\ .$$

Energy of the accelerated bunch in terms of voltage:

$$U = E_{S0}l\frac{1-e^{-\alpha l}}{\alpha l} - qcR_S l.$$

LBC value, when energy gain in terms of voltage equals 0:

$$q_{lim} = \frac{E_{S0}}{cR_S}\frac{1-e^{-\alpha l}}{\alpha l}.$$

Where E_{S0} – power source field, l – accelerating structure length, α – attenuation factor, R_S – series impedance.

The maximum dose rate absorbed in the air P_D from bremsstrahlung of accelerated electrons with bunch current equaled 1 mA and obtained on the distance of 1 m from the target with atom number Z could be defined with less than 4% tolerance by equation [3]:

$$P_D = P_{0Z}(Z) \times W^{d(Z)}.$$

Where P_D units are $Gy/(min \times mA)$, W units are MeV and a coefficient and a degree are defined by following expressions:

$$P_{0Z}(Z) = 0.144 + 7.38 \times 10^{-3} \times Z,$$

$$d(Z) = 3.19 - 6.9 \times 10^{-3} \times Z.$$

Consider a case of copper target (Z=29). $p_{0Z}(29) = 0.35802$, $d(29) = 2.9899$, $P_D = 0.358 \times W^3$.

Copper target is chosen due to simplicity of further calculations, since conversion is easy when $P_D \sim W^3$, i. e. in a degree of a whole number 3.

If consider a value of accelerated bunch pulse current I_0 (mA) then full dose rate at the exit of linear accelerator and copper target equals:

$$P_{fD} = 0.358 \times W^3 \times I_0. \qquad (1)$$

Expression (1) could be written with pulse current $I_0 = qc/\lambda$:

$$P_{fD} = 0.358 \times W^3 \times q \times c/\lambda.$$

Energy in voltage term is expressed through pulse current I_0 [2]:

$$U = E_{S0}l\frac{1-e^{-\alpha l}}{\alpha l} - I_0 R_S \lambda l. \qquad (2)$$

By adding expression (2) in (1) the expression for full dose rate becomes:

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$$P_{fD} = 0.358\left(E_{S0}l\frac{1-e^{-\alpha l}}{\alpha l} - I_0 R_S \lambda l\right)^3 \times I_0. \quad (3)$$

If derivative of equation (3) by I_0 equals 0:

$$\frac{dP_{fD}}{dI_0} = 0.358\left(E_{S0}l\frac{1-e^{-\alpha l}}{\alpha l} - I_0 R_S \lambda l\right)^2 \left(E_{S0}l\frac{1-e^{-\alpha l}}{\alpha l} - 4I_0 R_S \lambda l\right) = 0.$$

If the first bracet is equal to 0, then dose rate tends to be zero, since charge tends to limit value and energy tends to equal zero. Equality to 0 of a second bracket corresponds following expressions:

$$I_0 = \frac{1}{4} \times \frac{E_{S0}}{R_S \lambda} \times \frac{1-e^{-\alpha l}}{\alpha l},$$

$$q_{maxP_{fD}} = \frac{1}{4} \times \frac{E_{S0}}{cR_S} \times \frac{1-e^{-\alpha l}}{\alpha l} = \frac{1}{4} q_{lim}.$$

Thereby maximum dose rate could be achieved under LBC value, the charge value which would not obtain additional energy after passing accelerating structure [2]. Relation between dose rate and charge is shown on Fig. 1.

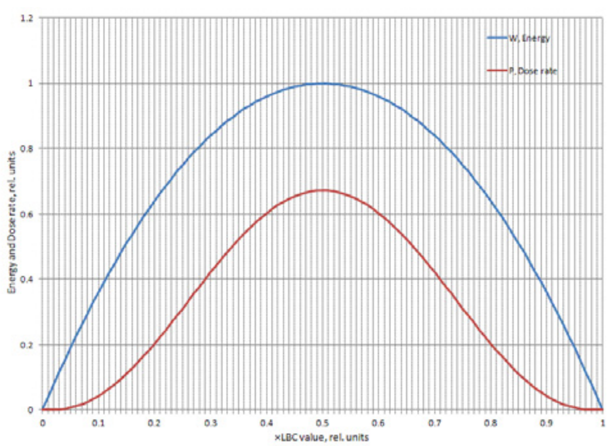

Figure 1: Energy of accelerated bunch and Absorbed Dose Rate of bremsstrahlung from tungsten target vs Bunch charge

CONCLUSION

Due to the non-traditional approach to the radiation of relativistic electron bunches, more accurate expressions of estimation of dose rate from bremsstrahlung radiated by copper target mounted at the exit of accelerating structure have been obtained. As a result, maximum dose rate is observed under limited bunch charge value. The calculation has been made for DLWG. Such approach can be used for other accelerating systems applied in linacs. If you have any questions reach me at qstpss@gmail.com please.

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