MAXIMUM VALUE OF THE STANDING WAVE AND TRAVELLING WAVE ACCELERATING STRUCTURES ELECTRONIC EFFICIENCY

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Abstract

A new theoretical approach to a calculation of the standing wave and travelling wave structures electronic efficiency is described. As a result the electronic efficiency of DLWG and biperiodic structure is evaluated regarding a new definition.

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 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 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. A detailed description is reviewed in [2]. According to the ideas of electronic efficiency of DLWG and biperiodic structure are defined below.

EVALUATION OF ELECTRONIC EFFICIENCY

Consider the accelerating section of electron linac based on DLWG with relative phase velocity $\beta_{ph} = 1$. Working modes are as a rule $\theta = \pi/2$ and $\theta = 2\pi/3$. An electromagnetic field is generated by two sources. A microwave generator which supplies accelerating section produces following electromagnetic field on DLWG axis [4, 5]:

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

Where E_{S0} is the accelerating field at the input of accelerating section.

The second source which generates the electrical field is an accelerated electron beam. A summary field radiated by a series train of pointed bunches with charge q after completion of the transient processes is equal to:

$$E_S = \frac{q v R_S}{1-e^{\frac{-\pi}{Q_L}}}.$$

Where R_S – series impedance and Q_L – loaded Q factor. It should be noted that the ideal case is considered when every bunch is placed in the maximum of the total decelerating field of all bunches and in the maximum of the generator accelerating field:

$$E = E_{S0} e^{-\alpha z} - \frac{E_q}{\left(1 - e^{\frac{-\pi}{Q_L}}\right)}$$

The energy obtained by every electron bunch at the exit of the accelerating section with length l equals (in terms of voltage):

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

Since the beam pulsed current is equal to $I_0 = q/T$ it can be written as:

$$I_0 = qc/\lambda.$$

And the expression for E_q takes the following form:

$$E_q = I_0 R_S \lambda.$$

The power of the accelerated electrons beam equals:

$$P = I_0 E_{S0} l \frac{1-e^{-\alpha l}}{\alpha l} - \frac{I_0^2 R_S \lambda l}{1-e^{\frac{-\pi}{Q_L}}}. \quad (1)$$

The electronic efficiency of the accelerating section correspondingly equals:

$$\eta = \frac{1}{P_0}\left[I_0 E_{S0} l \frac{1-e^{-\alpha l}}{\alpha l} - I_0^2 \frac{R_S \lambda l}{1-e^{\frac{-\pi}{Q_L}}}\right].$$

Consider the case when the beam power is maximal and the electronic efficiency of DLWG reaches the maximal value correspondingly. Determine the accelerated beam value when $P = P_{max}$. It is necessary derivative dP/dI_0 to be equaled 0. Then using (1) get current value I_0 when $P = P_{max}$:

$$I_0 = \frac{1}{2}\frac{E_{S0}}{R_S \lambda}\frac{1-e^{-\alpha l}}{\alpha l}\left(1 - e^{\frac{-\pi}{Q_L}}\right).$$

$$P_{max} = \frac{1}{2} P_0 \frac{l}{\lambda}\left(\frac{1-e^{-\alpha l}}{\alpha l}\right)^2 \left(1 - e^{\frac{-\pi}{Q_L}}\right).$$

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The dependence of the DLWG maximum electronic efficiency according to its length is presented on Fig. 1 with following parameters: $\theta = \pi/2$, iris is without rounding, $\lambda = 16.5\ cm$, $a/\lambda = 0.20$, $\alpha = 0.01492\ 1/m$ (copper), $Q_L = 3.1672$, $t/\lambda = 0.0382$.

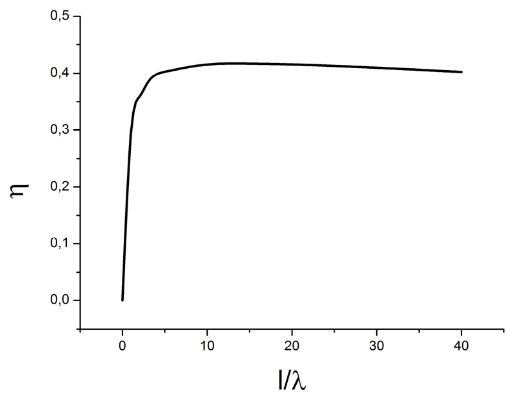

Figure 1: Dependence of DLWG electronic efficiency η from accelerating structure length

It should be noted that for the waveguide, chosen parameters the section length should not exceed 1 m. Even in this case it is desired to reach the maximum electronic efficiency. At this point the current length is $\eta = 0.45$ while the maximum η equals 0.46, when the waveguide length equals 3 m. In addition, if there are no losses in DLWG the electronic efficiency steadily increases up to $\eta_{max} = 0.50$. It is evident that the gain is not great: $l = 1\ m$ gives $\eta = 0.456$, and when $l \to \infty$ the $\eta = 0.50$.

Now consider the accelerating section of electron linac based on biperiodic system operating on standing wave [6]. Also the data of [5] are used for structures with $\lambda/2$ period.

For the reason of simplicity, accept the approach when the section is presented in the form of a cavity with common coupling elements and with supplying waveguide [6]. It is applied here, not the energetic approach to the computation of energy, power and accelerating system electronic efficiency as well as beam parameters but the field approach when the basis for the analysis is a superposition of the accelerating field produced by the power source and the beam radiation field.

It can be written that the reflection coefficient from the load equals:

$$R_C = \frac{1-\beta}{1+\beta} = \frac{R_L - Z_0}{R_L + Z_0}.$$

According to the definition, the power incoming into the load, i.e. the BDS, can be written as:

$$P = P_S(1 - |R_C|^2) = \frac{4\beta}{(1+\beta)^2} P_S. \qquad (2)$$

On the other hand it is known that:

$$P = \frac{1}{2}\frac{U_L^2}{R_L} = \frac{1}{2}\frac{(U_L m)^2}{R_{sh}} = \frac{1}{2}\frac{U_S^2}{R_{sh}}. \qquad (3)$$

Where U_S is the voltage in BDS produced by the power source.

By comparison of (2) and (3) obtain the voltage produced by the power source in BDS accelerating section (or cavity):

$$U_S = \sqrt{\frac{8\beta}{(1+\beta)^2} R_{sh} P_S}.$$

According to Wilson theorem [7], an electron bunch has the energy loss (in terms of voltage) U_L which one equals the half of the voltage applied to the gap U_{loss}. The latter equals the result of multiplication of the electron current by the cavity shunt impedance:

$$U_{loss} = \frac{U_L}{2} = \frac{J R_{sh}}{2} = I_0 R_{sh}.$$

Where $J = 2I_0$ is the field of the harmonic periodic series of bunches with charge q and interval equaled to the wavelength.

The voltage acts on electron bunches in BDS in case when bunches are situated on maximum of the power source accelerating field and naturally on maximum of own decelerating radiation field can be written as:

$$U = U_S - U_{loss}.$$

That is:

$$U = \sqrt{\frac{8\beta}{(1+\beta)^2} R_{sh} P_S} - I_0 R_{sh}.$$

The power transferred from the power source to the beam equals:

$$P = \frac{1}{2} J U = I_0 \sqrt{\frac{8\beta}{(1+\beta)^2} R_{sh} P_S} - I_0^2 R_{sh}. \qquad (4)$$

To determine of maximum value of the electron beam power in BDS, differentiate (4) by I_0 and equate the obtained expression to 0:

$$\frac{dP}{dI_0} = \sqrt{\frac{8\beta}{(1+\beta)^2} R_{sh} P_S} - 2 I_0 R_{sh} = 0.$$

For $P = P_{max}$ it gives:

$$I_0 = \frac{1}{2R_{sh}} \sqrt{\frac{8\beta}{(1+\beta)^2} R_{sh} P_S}. \qquad (5)$$

Determine $P = P_{max}$ by substitution of (5) into (4):

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$$P_{max} = \frac{2\beta}{(1+\beta)^2} P_S.$$

Correspondingly, the maximum value of electronic efficiency equals:

$$\eta_{max} = \frac{2\beta}{(1+\beta)^2}.$$

This dependence is shown on Fig. 2.

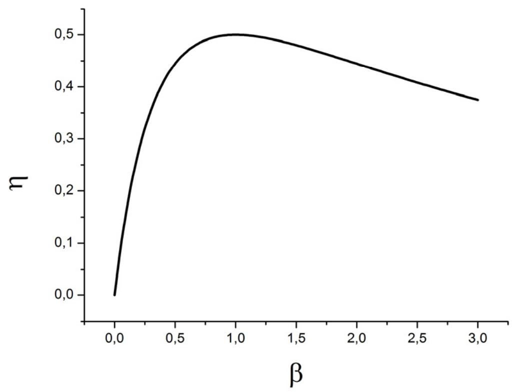

Figure 2: Dependence of biperiodic structure electronic efficiency η from coupling coefficient β.

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