BEAM CURRENT LIMITATION IN MICROWAVE ACCELERATORS

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Abstract

A simplified approach is used to estimate current limit in microwave electron linear accelerators based on the achieved electron concentration and space charge values. A number of examples, presented in the report shows that the proposed technique is applicable for preliminary calculations.

1. Introduction

It is well known that beam efficiency in X-band linear accelerators is rather low compared to S and L-band units. Usually, one wants to reach as high as possible beam energy value for a given amount of power from power source. Power from commonly used magnetrons does not exceed value of 2 MW. Current during pulse in X-band accelerators is usually below 50 mA, for some units value about 100 mA was observed. Besides, measured efficiency is usually lower than calculated value.

2. Power Consumption

If we assume, that power Pi injected into accelerator structure is partially lost in the walls (Pd) and the other part is stored in accelerated beam (Pb).

$$Pi=Pb+Pd, \qquad (1)$$

Beam efficiency value Be could be shown as

$$Be=1- Pd/Pi. \qquad (2)$$

Let us think that Pd is power value required to build the fields to achieve certain energy value Wo at no beam loading. This value of Pd is constant for a given structure. Now, if one increases power injected into the structure and try to maintain energy value at Wo while increasing beam loading, efficiency would tend to reach 100% value:

At the extreme, if Pd/Pi=0, Be=1 .

Indeed, this is a crude model of power balance.

3.Electron density of a bunch

In practice, beam value is limited by a number of factors. To simplify our further calculations, we will assume that bunch has a cylindrical shape with radius Rb and length Lb.

Bunch volume is

$$Vb=3.14 \times Rb^2 \times Lb. \qquad (3)$$

Charge stored in a bunch is

$$Qb=I/F=Vb \times N \times e, \qquad (4)$$

where I-beam current;
F-frequency,
N-number of electrons per unit volume;
e-charge of electron.

Therefore,

$$I = 3.14 \times Vb \times Lb \times N \times e \times c/Wl , (5)$$

where Wl-wavelength.

Statistical limit value of N is 10^9 $1/cm^3$. For reference, this means that electrons in a bunch are at 4000xRe from each other (Re-classical radius of electron).

Equation (5) lets us estimate limit current in accelerators at various wavelengths and aperture radius.
For maximum beam radius is about 50% or accelerators aperture and bunch length of 0.25Wl

$$I\,[A] =(a/Wl)^2.Wl^2[cm]. \qquad (6)$$

Surprisingly, these simple calculations led us to some quite realistic numbers.

Table 1. Limit current at various apertures in X band.

2a,mm	4	8	12	16
I,mA	40	160	360	640

Table 2. Limit current at various wave lenghts for a/Wl=0.1

Band	X	S	L
Wl, cm	3	10	20
I, A	0.1	1	4

Practical values are somewhat lower, as in practice Lb< 0.25Wl and beam radius is less than it was assumed.

Table 3. Experimentally measured current values in various X-band linacs.

	Aperture, mm:	Experiment :	Estimated
MINAC-6	: 4.7	: 50	: 75
U-34	: 5	: 27	: 75
U-35	:10(aver)	: 100	: 250

Conclusions

Some statistical data are used to explain low efficiency in X-band accelerators compared to S and L band. Numbers show, that approach to X-band accelerator design is usually done to get maximum energy for a given power value and sacrifices, therefore, with efficiency.