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Beam Loading in a High Current Accelerating Gap*

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Abstract

Energy exchange between a high-current beam and a source at an accelerating gap is treated with a simple transmission line theory. There exists a matching condition for which the beam energy gain is equal to the source voltage. The total energy gain in a multigap system is expressed in terms of individual source voltages and the beam current.

I INTRODUCTION

Recently, multigap high-current accelerators[1,2] have attracted considerable attention because of their potential applications in diverse areas. Unlike a low current beam in the conventional accelerators, a high-current beam accompanies a substantial amount of field energy. Thus, as a high-current beam passes through an accelerating gap, the energy transfer takes place not only from the source to the beam but also from the beam to the source. The latter is easily ignored in the low-current accelerator systems.

In this work, the energy exchange between a beam and a source at an accelerating gap is treated with a simple transmission line theory. The beam energy gained as it passes through the accelerating gap is expressed in terms of the source voltage, the beam current, and the characteristic impedance of the transmission line. There exists a matching condition at which the accelerating voltage is equal to the source voltage. The analysis is extended to a case where the accelerating gap is shunted with a resistor. The beam energy gained in a multigap accelerator system is expressed in terms of relevant parameters.

II TRANSMISSION LINE MODEL

The interaction between a beam and an accelerating gap may be described with a discontinuity in a transmission line in which the beam terminates the end of the transmission line as shown in Fig. 1. As a pulse produced by a pulsed power source arrives the discontinuity, continuities are required of the voltage and current from the transmission line to the beam (Kirchhoff's voltage and current laws). We consider a case when a pulse of constant amplitude, V_S, from the source and a beam current of constant amplitude, I_B, are arriving at the gap simultaneously. The voltage and current of the pulse are related by $V_S = I_S Z_0$ in the transmission line, where Z_0 is the characteristic impedance of the transmission line. The boundary condition that the sum of currents at the discontinuity equals zero necessitates a reflected pulse I_- such that

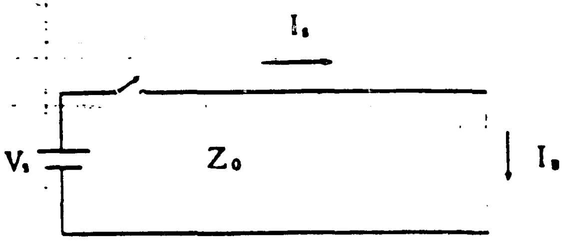

Figure 1: Schematic representation of an accelerating gap and a high-current beam.

$$I_S + I_- = I_B, \tag{1}$$

where the voltage of the reflected pulse is given by $V_- = -I_- Z_0$. The beam experience a accelerating voltage, V_B, which is the sum of voltages of the incident and reflected pulses appearing across the gap given by

$$V_S + V_- = V_B. \tag{2}$$

Eliminating I_- and V_- from Eqs. (1) and (2), one finds

$$V_B = (2I_S - I_B)Z_0. \tag{3}$$

It is apparent from Eq. (3) that the voltage across the beam, V_B, which is the accelerating voltage, is not always equal to the source voltage $V_S = I_S Z_0$. The matching condition for which the accelerating voltage is equal to the source voltage, $V_B = V_S$, is only when

$$I_{Sm} = I_B \quad \text{or} \quad V_{Sm} = I_B Z_0, \tag{4}$$

i.e., the source voltage is equal to the beam current times the characteristic impedance. Under this condition, the full energy transfer takes place from the source to the beam. This result is illustrated in Fig. 2. It is interesting to note that when $V_S = 0$, Eq. (3) reduces to $V_B = -I_B Z_0$

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