# REDUCTION OF BEAM BREAKUP GROWTH BY BLEEDING CAVITIES IN LINEAR ACCELERATORS

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## ABSTRACT

We show that, by coupling several dummy (bleeding) cavities to the accelerating cavities in a linear accelerator, beam breakup growth may be reduced significantly, by factors of hundred in some examples. This growth reduction results from the sharing of the deflecting mode energy in the accelerating cavities with the bleeding cavities. Some issues on the viability of this novel method of BBU control are discussed.

## I. INTRODUCTION

There are three known types of rf cure to control beam breakup (BBU) growth: (1) Lowering of the quality factor Q of the deflecting modes, such as by adding transverse slots to the cavities [1] or by loading the cavities with ferrite material [2,3], (2) Reducing the transverse shunt impedance that the beam experiences, e.g., by the use of a shielded gap [4,5], and (3) Stagger tuning the cavities, so that the breakup mode frequencies are off-tuned from one to the next [6-9]. Here, we consider a fourth possibility: (4) By simply attaching to the main accelerating cavities several identical dummy (bleeding) cavities so that the main cavities' deflecting mode (that causes the beam to deflect sideways), has its mode energy shared by the dummy cavities to which it is coupled. This method of BBU control, in some sense, is similar to mechanism (2), but it has the advantage that all deflecting modes can be controlled, as identical cavities are employed. It is different from mechanism (1), as it does not involve any dissipative process.

We stumbled on the above mentioned mechanism while we assessed the effects of cross-coupling among cavities [10] in a recirculating accelerator known as the Spiral Line Induction Accelerator (SLIA) [11]. By unwrapping the SLIA into a linac, we show here that the addition of bleeding cavities would reduce BBU growth in a linac geometry.

## II. MODEL AND RESULTS

For simplicity, consider a continuous coasting beam of current I, relativistic mass factor $\gamma$, pulse length $\tau$, in a linac which consists of N identical accelerating cavities. Each accelerating cavity supports a deflecting mode of frequency $\omega_0$, quality factor Q, and transverse shunt impedance $Z_\perp$. At the ith accelerating cavity, the deflecting mode amplitude is $f^{(i)}(t)$, and the beam's transverse displacement there is $x^{(i)}(t)$. Each accelerating cavity is coupled to several dummy cavities [Fig. 1]. The deflecting modes in these dummy cavities are denoted by $g_1^{(i)}(t)$, $g_2^{(i)}(t)$, etc. For simplicity of notation, we shall drop the superscript (i) unless specified otherwise.

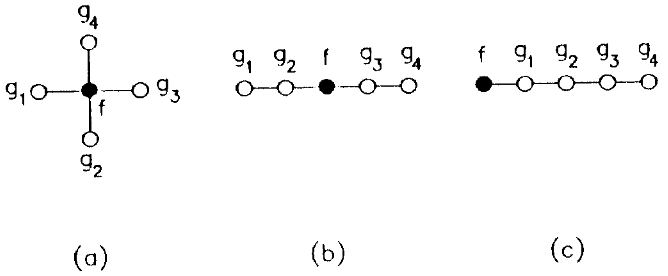

Fig. 1. Various coupling configurations between a typical accelerating cavity (solid circle) and the bleeding cavities (open circle).

The accelerating cavity can be coupled to the dummy cavities in many different ways. Figure 1 shows three configurations where an accelerating cavity (solid circle), is coupled to four dummy cavities (open circles). We assume that the coupling constant between each pair of cavities is $\kappa$ [10]. The governing equations for configuration b, for instance then read

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$$
\begin{aligned}
Lf(t) &= \varepsilon_r h(t)x(t) + \kappa g_2(t) + \kappa g_3(t) \\
Lg_1(t) &= \kappa g_2(t) \\
Lg_2(t) &= \kappa f(t) + \kappa g_1(t) \qquad (1) \\
Lg_3(t) &= \kappa f(t) + \kappa g_4(t) \\
Lg_4(t) &= \kappa g_3(t)
\end{aligned}
$$

where L denotes the operator

$$L \equiv \frac{d^2}{dt^2} + \frac{\omega_o}{Q}\frac{d}{dt} + \omega_o^2,$$

$\varepsilon_r = (I/17\gamma kA)Z_\perp(\Omega)/30Q$ is the dimensionless coupling constant, and $h(t)=1$ when the beam is present within the accelerating cavity and $h(t)=0$ otherwise. The term $\varepsilon_r hx$ in Eq. (1) describes the excitation of the breakup mode in the accelerating cavity by the beam's transverse displacement. The remaining terms in the RHS of Eq. (1) describe the cavity excitation as a result of the coupling ($\kappa$). Similar models have been used to describe the mode coupling in two identical cavities, e.g., in a conventional two-cavity klystron oscillator, where $\kappa$ equal to a few per cent has been routinely used [12].

Upon crossing the ith accelerating cavity at time t, a beam slice would pick up an incremental transverse momentum $\Delta p^{(i)}(t) = f^{(i)}(t)$; its transverse displacement remains unchanged for a narrow gap. We assume that the motion of this beam slice, upon exiting the ith cavity, will be advanced to the (i+1)th cavity via a 2×2 transport matrix.

As an example, we unwrap a 7-turn, 70 cavity recirculating accelerator, that models a SLIA Upgrade, into a linac with 70 accelerating cavities, each of which is connected to four dummy cavities as shown in Fig. 1. The parameters for the SLIA Upgrade were given in Ref. 13; briefly, 10 kA beam current, 35 ns pulse length, 25 MeV energy, $\gamma\varepsilon_r = 0.245$.

In Fig. 2 we show the BBU amplitude gain, x(70)/x(1), at the 70th cavity as a function of $\kappa$ for configurations (a), (b), (c). Note from this figure that reduction of BBU growth up to a factor of 300 is possible if $\kappa \to 0.1$.

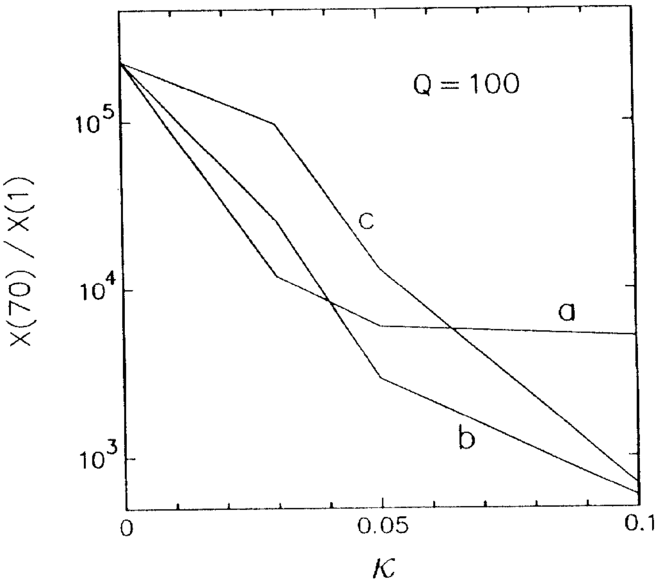

Fig. 2. BBU amplitude gain as a function of $\kappa$ for the three configurations shown in Fig. 1.

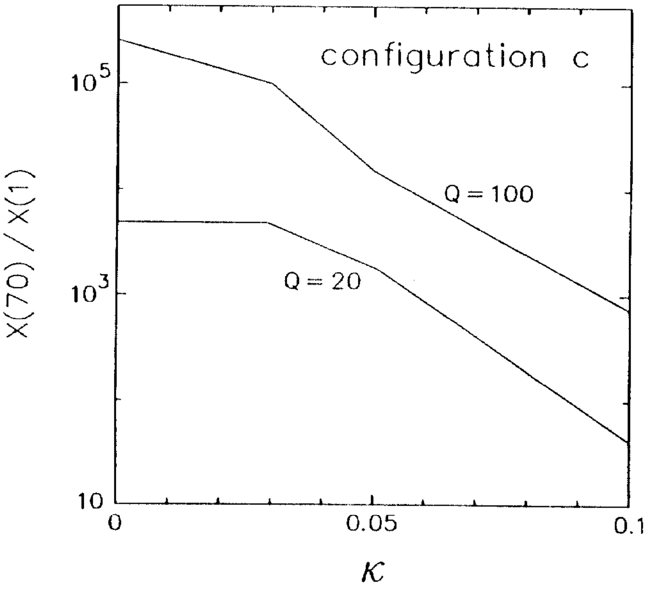

Fig. 3. Comparison between the cases of Q=100 and Q=20 for configuration c.

We have set Q = 100 in Fig. 2 and we include the data for Q = 20 in Fig. 3, for configuration C. In Fig. 4, we eliminate the "bends" in the SLIA Upgrade so that, when it is unwrapped into a linac, all seventy cavities have equal separation. Here, we see that the reduction of BBU growth is only moderate.

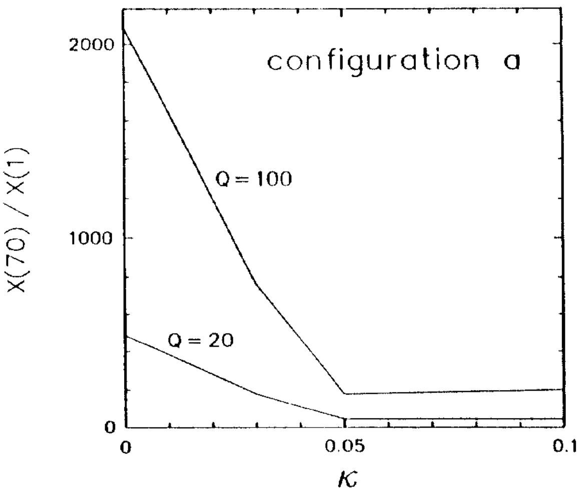

Fig. 4. Comparison between the cases of Q=100 and Q=20 for configuration a. Here, the accelerating cavities have equal separation.

The above data supported the general conclusion that bleeding cavities can reduce BBU growth. The amount of reduction depends on the geometrical arrangements of the accelerating cavities and the bleeding cavities. In general, the amount of BBU reduction increases with Q, as in our previous studies [10].

## III. SOME ISSUES

Many questions may undoubtedly be raised regarding this method of BBU control. (1) Would the dummy cavities actually worsen BBU growth, as their presence introduces asymmetries to the accelerating cavity, where the beam passes through? (2) Would the dummy cavities lower the acceleration gradient, as they may also provide leakage of the power intended for particle acceleration? (3) What is the proper way to control the degree of cavity couplings? Would coupling loops suffice? (4) The method of couplings may vary. For example, should mode $g_1$ be coupled to mode $g_4$ in Fig. 1, and what determines the optimum configuration? (5) In the above formulation we have assumed that all κ's are the same. How would different phasings in the cavity coupling influence BBU growth? (6) Should this method of BBU control be applied to linear colliders or more suitably to high current induction accelerators [14]? (7) How about the cost of this method of BBU control in comparison with other rf cures?

Although these questions cannot be answered by the present cursory study, some of them can be addressed by small scale experiments, especially those concerning the methods of cavity couplings and their purported tendency of reducing BBU growth. The usefulness of this seemingly novel method of BBU control may then be further assessed, once such small scale experiments are performed [15].

## ACKNOWLEDGMENT

This work was supported by the Strategic Defense Initiative Organization, managed by the Office of Naval Research. It was also supported by the Defense Advanced Research Project Agency under ARPA Order 7781 and monitored by the Naval Surface Warfare Center.

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