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Multi-stage wake-field accelerator

Wei Gai
Argonne National Laboratory, Argonne, IL 60439

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In the past few years, many wake-field acceleration schemes have been proposed, which can be classified into two categories. The first one is the wake field transformer such as T. Weiland's scheme[1]. The second one, we will mainly emphesize here, is the co-linear wake field accelerator such as the plasma wake field accelerator[2], wakeatron[3], dielectric wake-field accelerator[4] etc. It can be shown that provided the driving beam is sufficiently intense, a few hundred MeV/m acceleration gradient can be achieved. Proof of principle experiments for colinear wake field accelerators have already been performed[5] [6] [7]. For a colinear accelerator, there is a fundemental theorem ("wakefield theorem")[2], which states that the maximum energy gain per particle of the accelerated beam can not exceed twice the energy loss per particle of the driver beam. Simply stated, this says that the transformer ratio R can not be greater than two. This theorem complicates the practical applications of wakefield accelerators, especially for high energy linear colliders. Many ideas have been proposed to overcome this problem, for example, non-linear effects in the plasma[8] and dielectric wakefield accelerators[9], but non-linear processes in wakefield devices are very complicated phenomena and have not been fully explored[9]. Shaping the driving beam profile would increase the transformer ratio as discussed by many people[2] [4], but the electron pulse shaping technology has yet to be developed. Also, as pointed out by J. Simpson[10], high transformer ratio devices will have relative low accelerating gradient.

In this paper we propose a multi-stage wake field acceleration scheme to overcome the low transformer ratio problem and still provide high accelerating gradients. The idea is very simple. We use a train of several electron bunches from a linear accelerator (main linac) with well defined separations between the bunches (tens of ns) to drive wake field devices. Here we have made the assumption that the wake field devices are available, whether plasma, iris-loaded metallic or dielectric wake field structures. This scheme can be varied in many ways. One example is shown in the figure. The heart of this idea is using a single linac to produce a train of driving bunches instead of many small linacs.

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The total energy gain of the accelerated beam in the wake field device is $E_{total} = nR\eta E_{drive}$, where E_{total} is the final energy of accelerated beam, n is the number of driving bunches,η is fraction of energy removed from driver and E_{drive} is the energy of the driving bunch. The way this works is to inject one driving bunch at a time into the wake field device, with the accelerated beam injected immediately in the device with appropriate separation so the maximum energy gain can be achieved. After each stage of acceleration, the driving beam will have lost almost all its energy and will be deflected into a dump, while the much higher energy accelerated beam is nearly unaffected. A second driving beam is injected immediately ahead of the accelerated beam at the beginning of the second stage. This process is repeated until until the very high energy accelerated beam is obtained. For example, we inject beam 1 at point a, beam 2 at b, 3 at c, and so on. In order to phase the second beam relative to the accelerated beam accurately, the second beam transport line must be shorter than the first by the distance between these two bunches. As we can see from the figure, the beam transport line from main linac to wake field accelerator can be pulse compression line.In this case the pulse length in the main linac can be relatively long, placing less stringent demands upon the performance of the drive beam linac.

The following is an example parameter list for a 500 GeV collider,

1. Main Linac (L-band) to produce driving beam:

Charge per driving bunch	$Q = 60 - 100nC$
rms pulse length of driving bunch	$\sigma_z = 3mm$
Acceleration gradient in the main linac	$G = 20MeV/m$
Energy of the beam	$E = 25GeV$
Reptition rate	$f = 100 - 1000Hz$
RF pulse length from driving klystron	$\tau(rf) = 2\mu s$
Seperation between the pulses	$d = 50ns$
Total number of driving pulses	$N = 10$
Fraction of drive beam energy removed	$\eta = 1$

2. Pulse compression and transport lines:

Driving beam bunch length after compression	$\sigma_z = 0.7mm$
Path length differece of each line	$\delta_l = l_n - l_{n+1} = 50nS$

3. Wake field device:

Acceleration gradient	$G = 125 - 500MeV/m$
Length of each stage	$l = 100 - 400m$
Total length of the device	$1 - 4km$
Transformer ratio	$R = 2$
Final energy output	$500GeV$

The above parameters are variable for different design. The advantage of this scheme is simple, and it also can be used for a low energy machine, for example one could have 1 GeV beam by using 150 MeV electron linac with 5 stages of wake field device. One should point out technical difficulties of building such machine is timing of each pulses and the kicker magnets to inject each beam into the wake field device.

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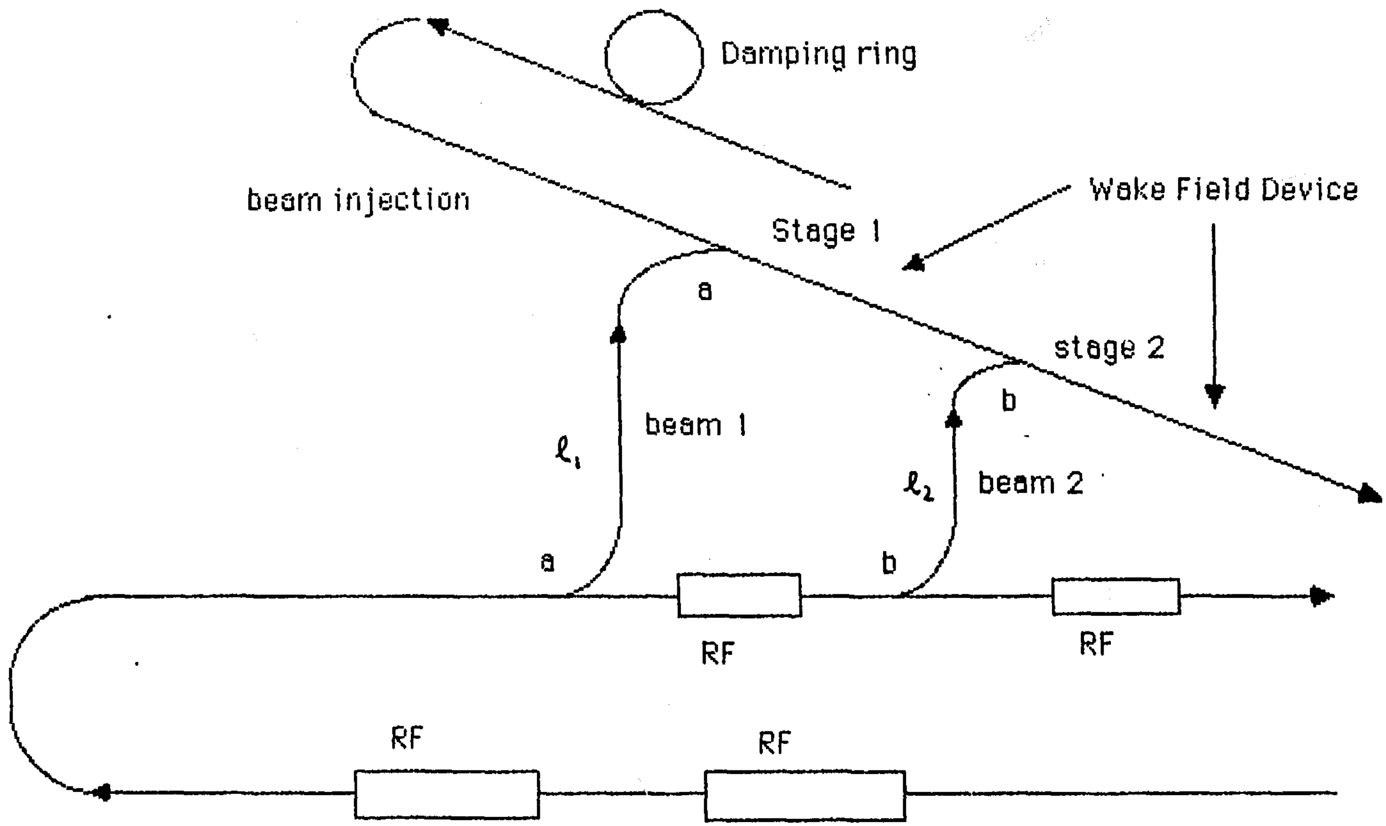

Main Linac (L Band)