# A WAKE FIELD ACCELERATOR

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## Abstract

In a wake field accelerator the electromagnetic fields of a very short high intensity electron bunch are used to accelerate a second low intensity electron bunch to very high energies. By using special accelerating structures which concentrate the fields of the high intensity bunch at the location of the second low intensity bunch one can produce accelerating gradients of the order of 200 MV $m^{-1}$, which are a factor of 10 larger than the fields which decelerate the high intensity bunch.

An experiment is presently being set up, in which this new accelerator scheme will be tested. The high intensity bunch will be in the form of an electron ring (6 cm Ø, ring thickness 2 mm, charge 1 μCoul) which is to be accelerated to an energy of 8 MeV before it in turn is used to accelerate a smaller charge to energies of 90-100 MeV. Status and lay-out of this experiment will be described.

## Introduction

The next generation of ultra high energy electron-positron colliders, after the completion of the large LEP-storage ring at Geneva, will very likely be linear colliders. For large circular electron machines the scaling law of cost vs. energy is quadratic. The cost of a linear collider on the other hand will increase linearly with energy. At single beam energies somewhere between 150 and 300 GeV, linear colliders may become more economical than storage rings. But in order to make ultra high energy colliders financially feasible, unit costs will have to be much lower than those of today's linear accelerators. One possible way to accomplish that could be much higher gradients in the accelerating structure than those obtainable in today's electron linacs.

The wake field accelerator [1)] might reach average accelerating gradients which are one order of magnitude higher than those in conventional linac structures. In a wake field accelerator a high current beam of modest energy excites electromagnetic wake fields in a suitable accelerating structure which in turn act on a second beam. By choosing special geometries for the high current beam and the accelerating structure the accelerating fields seen by the second beam will be much higher than those which decelerate the primary beam. The device may be compared to a transformer, in which a large current of small voltage drives a small current with high voltages. The "transformer ratio" in a wake field accelerator may be 10 or higher.

Among the many possible geometries of the primary beam and the accelerating structure we have especially analysed a hollow beam of very short bunch length going at speeds of $v \approx c$ through a structure as shown in Fig. 1. The electromagnetic wake fields of such a beam will be reflected at each circular slot and travel to the center of the structure. As the diameter of such a concentric wave decreases the field strength increases. When the wave has reached the center of the structure a second bunch, also of very short length, might pass on the axis and will be accelerated by the very high fields. Since both beams - the driving outer beam and the driven inner beam - are extremely relativistic, both beams will keep their relative phase with respect to each other independent of their respective energies. The exact dimensions of the accelerator structure are obviously much less critical than those of the highly dispersive conventional linac structures.

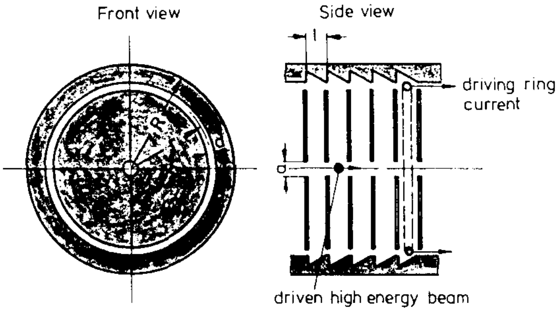

Fig. 1 Structure of a wake field transformer

## The Wake Field Accelerator

The shape and strength of the central accelerating field was calculated with the help of the BCI-computer code [2)] (this program is a numerical integration of Maxwell's equations in space and time). For a given longitudinal Gaussian distribution of the hollow driving beam the influence of the following parameters on the "transformer ratio" and the central field strength was calculated and optimized: The ratio of the radius of the hollow beam to the inner radius of the structure r/R, the spacing of the discs $\ell$, the width of the circular slots d and the diameter of the central hole a. One possible set of parameters is as follows:

$R$ = 3 cm

$r$ = 2.6 cm

$\ell$ = 0.4 cm

$d$ = 0.2 cm

$a$ = 0.4 cm

$\delta$ = one standard deviation of the bunch length of the driving beam = 0.2 cm

$Q_d$ = charge in the bunch of the driving beam = $10^{-6}$Coul

$E_d$ = max. decelerating field as seen by the driving beam = 35 MV $m^{-1}$

$E_a$ = max. accelerating field as seen by the driven beam = 250 MV $m^{-1}$

$E_{bl}$ = additional decelerating field of the driven beam due to its beam loading = 15 MV $m^{-1}$

Fig. 2 shows the field strengths of the driving and the driven beams. After the wakefields of the ring current were concentrated on the axis of the structure they move radially outward again and are reflected at the outer tube wall. At the second time at which they concentrate on the axis their sign is reversed which makes it possible to accelerate positrons. Dispersive effects though have lowered the maximum amplitude somewhat as can be seen in Fig. 2.

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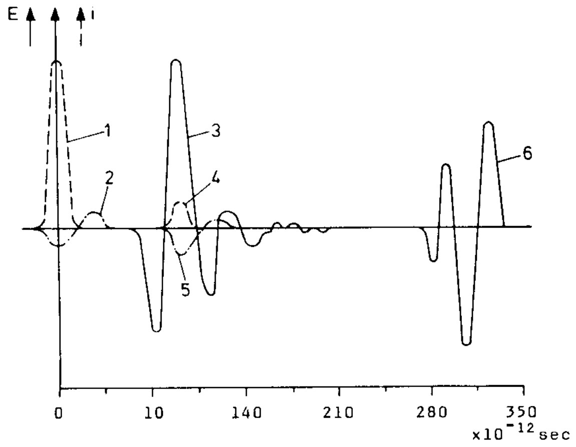

Fig. 2 Wake fields and current distributions

1.) current distribution of driving beam (total charge $Q_b$ = 1 μCoul)

2.) decelerating wake field acting on the driving beam, $E_{d\,max}$ = 35 MV $m^{-1}$

3.) accelerating wake field on the center axis $E_{a\,max}$ = 250 MV $m^{-1}$

4.) current distribution of driven high energy beam ($10^{11}$ particles per bunch)

5.) decelerating wake field produced by the central high energy beam $E_{bl}$ = 15 MV $m^{-1}$

6.) accelerating wake field on the center axis after first reflection at the outside wall (the inverted polarity may be suitable for acceleration of positrons)

If the driving beam does not have perfect uniform circular charge symmetry centered on the axis, transverse deflecting fields will result which might lead to a beam loss of the driving outer beam or the accelerated central beam[3]. In order to stabilize both beams against the effects of such imperfections a homogeneous longitudinal magnetic field can be used such that the ideal particles travel along the magnetic field lines. While such a field may be sufficient to stabilize the outer beam, the central beam may - depending on the deviations from ideal conditions - require some additional quadrupole focusing for stability.

## Wake Field Acceleration Experiment

In order to study the problems of such a wake field accelerator it was decided to test this idea in a very short test section. Fig. 3 and Fig. 4 show the principal arrangement of this experiment which is presently being assembled:

- The ring charge will be produced by photo effect on a ring cathode. The light of a laser (pulse power of 60 MW) falls on a conical prism and is reflected from there onto the ring cathode.

- The laser pulse of 2 nsec length is applied when the cathode is pulsed to - 150 kV.

- The photo current pulse is energy modulated in a prebuncher cavity and compressed to a pulse length of about 10 cm at the end of a drift space.

- Further compression and acceleration takes place in four 3-cell accelerating cavities, at the end of which the toroidal bunch will have a length of 3 cm, a ring thickness of 2 mm and an energy of 8 MeV.

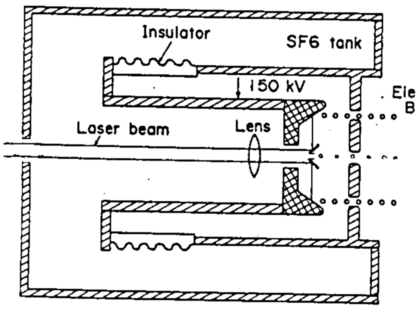

Fig. 3 Schematic lay-out of the ring shaped gun driven by a laser

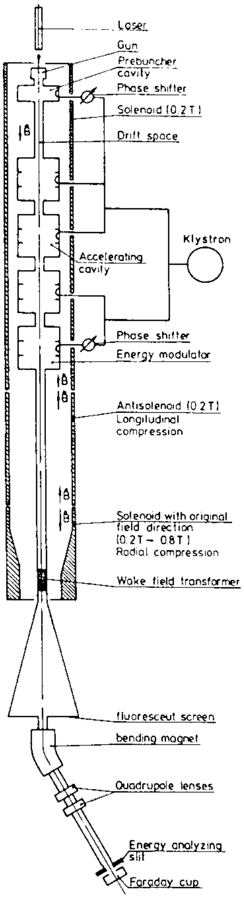

Fig. 4 Wake field accelerator experiment (schematic)

In the following drift space the homogeneous longitudinal magnetic field is opposite to that at the cathode and the accelerator. The bunch will therefore start to rotate, still keeping its dimensions. If the last of the 4 accelerating cavities has been properly phased such as to produce a longitudinal energy modulation in the bunch, further longitudinal compression will take place down to a bunch length of a few millimeter. At the end of this drift space the magnetic field is reverted back to its original direction such that the rotation of the bunch stops. Subsequent radial compression is accomplished by an increase of the magnetic field to 0.8 Tesla. The ring current is now ready to enter the 40 cm long wake field acceleration section. Those parts of a central beam which have the right longitudinal spacing to the driving outer beam should be accelerated and will subsequently be energy analyzed: The high energy central beam will be deflected and focused on an energy analyzing slit while the outer ring current rapidly expands when it leaves the longitudinal magnetic field. Its energy spectrum may be determined on the screen in front of the analyzing magnet.

The main anticipated difficulty with this experiment is the production of a ring current of sufficiently small dimensions and large charge. The longitudinal magnetic field is expected to controll sufficiently well transverse space charge effects. Control of longitudinal effects is considerably more difficult. A tracking program has been written to investigate the effects of higher order mode excitation in the cavities and longitudinal space charge effects within the bunch[3,4,5]. It seems important to wait with the final longitudinal compression until the beam is close to the speed of light. Another important aspect is the uniformity of the ring charge and its alignment with respect to the central beam . It is expected, that for this experiment the longitudinal magnetic field will be sufficient to stabilize the central beam and additional focusing will not be necessary.

At present first tests of the photo cathode have started, while the other parts of the experimental set-up are in various stages of assembly.

## Literature

/1/ G.-A. Voss and T. Weiland, "Particle Acceleration by Wake Fields", DESY-M-82-10, April 1982 and DESY 82-074, November 1982

/2/ T. Weiland, Proc. of the 12th International Conf. on High Energy Accelerators, Geneva 1980, p. 570-575 and DESY 82-015, March 1982

/3/ T. Weiland and F. Willeke, "Particle Tracking with Collective Effects in Wake Field Accelerators"

/4/ M. Leneke, unpublished work on space charge tracking codes

/5/ K. Bane and T. Weiland, unpublished work on space charge tracking codes