Computer Simulations of the Wake Field Transformer Experiment at DESY

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Abstract

The Wake Field Transformer Experiment at DESY has always been accompanied by theoretical studies on beam dynamics. The dynamics of the hollow driving beam of the *Wake Field Transformer* were studied by computer simulations. The computer codes WAKTRACK, a tracking code with collective effects, and TBCI-SF, a particle in cell code, are described and some example output is shown.

Introduction

In order to study the dynamics of the hollow driving beam of the *Wake Field Transformer* [1,2], two computer codes have been developed. We give here a short description of the computational methods used in these codes. Then we focus on the application of these codes to the Wake Field Transformer Experiment at DESY. The experimental setup is shown in figure 1. After the hollow beam has been accelerated to 8 MeV a further longitudinal compression is achieved in an antisolonoid. The field strength of the solenoid and of the antisolenoid are equal. In order to create a region where the field is radial, very short iron plates are inserted between the coils. These radial fields deliver an azimuthal kick to the particles as the beam goes through. Since the hollow beam is now rotating some of the energy goes into the circular motion and the longitudinal velocity decreases, i.e. the phase changes. By choosing an appropriate phase for the last cavity the hollow beam can now be compressed. At the end of the antisolenoid the rotation is stopped by an inverse kick. Then the beam enters the Transformer. As example output from the tracking code WAKTRACK, figure 2 shows a computer simulation of the beam trajectories until they enter the transformer. The code TBCI-SF, a particle in cell code, is used here as a design tool for the transformer, figure 3 shows some typical plot.

The Tracking Code WAKTRACK

The particle trajectories in a given structure consisting for example, of several cavities, drift spaces and solenoid coils are calculated by the tracking code WAKTRACK [3]. As this code is fast enough (< 1 min CPU on an IBM 3084Q for a typical run) to be used in parallel with the experimental work, currents in the solonoid coils can be optimized in order to guide the hollow beam through the linac. Figure 2 shows a typical plot. In the upper frame of the figure the energy and the phase of the particles are plotted. Immediately below these curves the structure, the cavities with their phases and the solenoid coils are drawn. The lower curves represent the particle trajectories.

The integration of the equations of motion for the particles is carried out with z, the axis of the linac, as a independent variable. Wherever possible analytical methods are used to speed up the algorithm. Inside a cavity, the program uses standardized URMEL [4] results on a 2-dimensional r-z-mesh as input data. Static electric and magnetic fields, as calculated by PROFI [5], are also accepted.

The speciality of the code WAKTRACK is that it includes collective space charge and wake fields effects. These are treated using a Greens functions approach. For simple structures like a long pipe, analytical results are used. In more complex structures a pseudo Greens function is calculated by TBCI [6]. Since z is the independent variable of integration the Greens functions approach uses the following approximation : A spatial distribution of the charge in the bunch must be calculated from the time and energy distribution of the particles. This implies that the particles pass the structure at constant velocity, which is a good approximation in the high energy region of the linac.

For more detailed investigations of the particle dynamics a particle in cell code has been developed, which is described in the next section.

The Particle in Cell Code TBCI-SF

The method of solving Maxwell's equations and the Lorentz equation in a self consistent way has been developed in plasma physics [7] and has been used recently in accelerator physics for high current beams. TBCI-SF [8] has been developed as an extension of TBCI [6].
After the initial conditions have been fixed, the following three steps are carried out in turn:

- Calculate the current density at the mesh points which corresponds to the motion of the particles.
- Advance the fields in time using this current density as a driving term. (equivalent to 1 step in TBCI)
- Advance the particle trajectories according to the Lorentz force.

Using the finite integration theory [9], the fields and the current density are allocated in the mesh. Then Maxwell's

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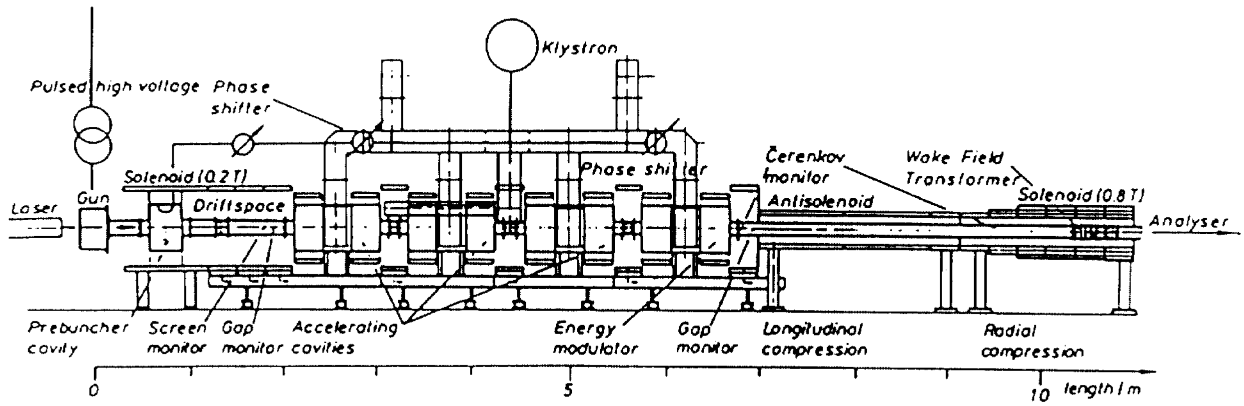

Fig.1 Overall layout of the Wakefield Experiment shown from left to right: Laser driven hollow beam gun, prebuncher, four 500 Mhz 3-cell cavities, antisolenoid (high energy buncher), Wake Field Transformer

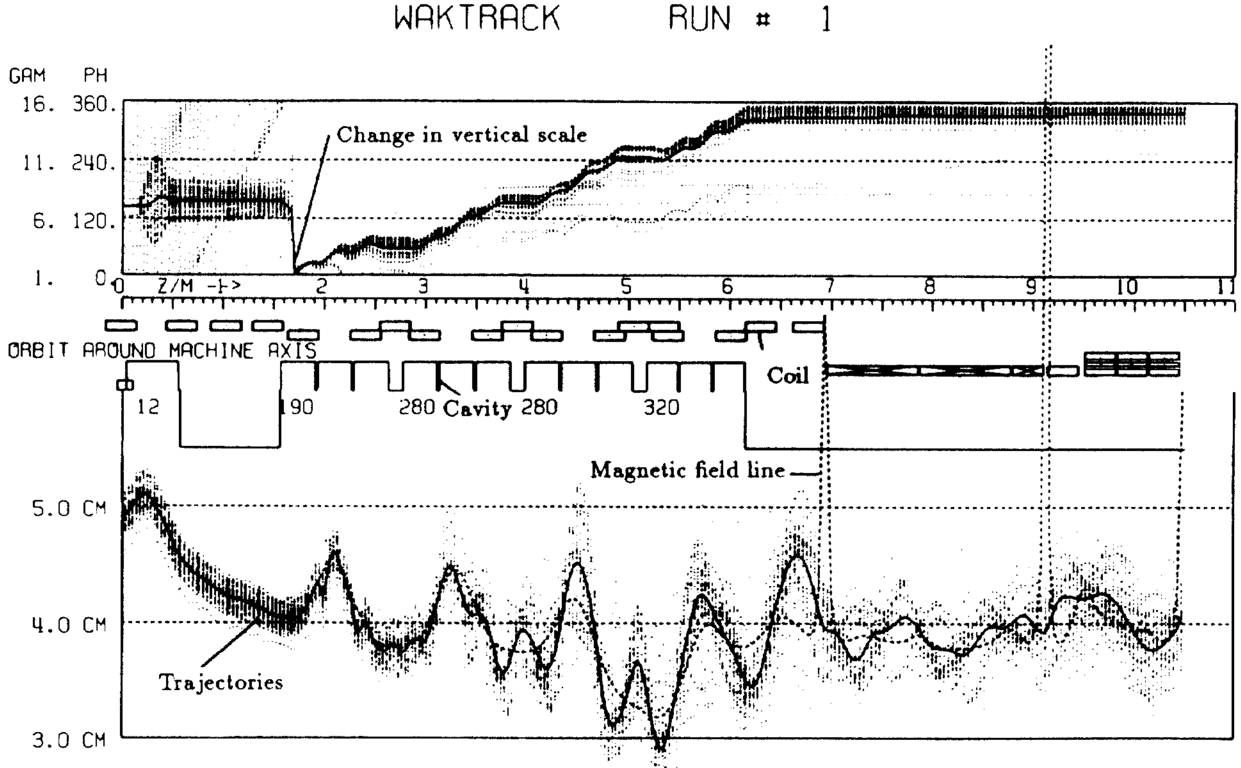

Fig.2 Example Output from WAKTRACK. In the upper frame, the energy (γ) and the phase of the particle are drawn. Directly below is, the scheme of the experimental set up is drawn. In the lower frame, the trajectories of the particles are shown.

equations are solved by a leap frog scheme. Deeper discussions of this algorithm can be found elsewhere [6].

The charge distribution in the bunch is described in TBCI-SF by macroparticles. The position of these particles may be anywhere inside the region covered by the mesh, their momentum is treated fully 3-dimensionally. The Lorentz force equation can be solved by a leap frog scheme assigning the position to half time steps and the momentum to full time steps (For details see ref. [8]).

External fields created by sources apart from the bunch current itself often cause problems in particle in cell codes. Sometimes, static fields are not foreseen and RF cavity fields can only be produced by simulating the whole filling period or by using other approximations. TBCI-SF allows external fields to be defined as start values for the electromagnetic field allocated to the mesh. Once they are set up, they do not need to be treated separately. Static fields may be precalculated by PROFI [5] and resonant fields by URMEL [4].

The CPU time needed for the simulation is a function of the number of macroparticles used, n_M, and of the number of meshpoints, n_P:

$$t_{CPU} = (a\frac{n_M}{1000} + b\frac{n_P}{1000}) \cdot \frac{\text{number of steps}}{1000}$$

On an IBM 3084Q the coefficients are $a \approx 13.5sec$ and $b \approx 160sec$.

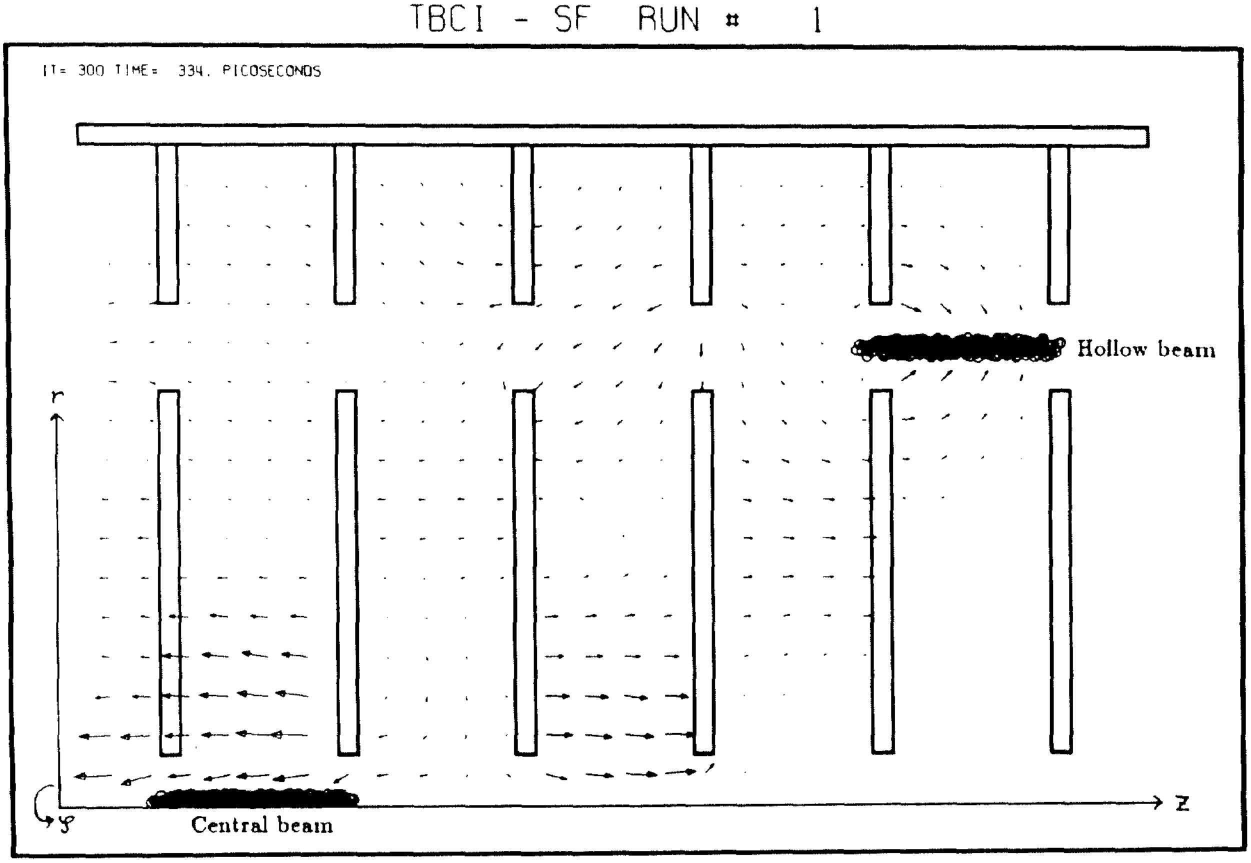

Fig.3 Typical Output from TBCI-SF: Wakefield Transformer . The electric field and the particle positions are plotted in the structure. The centre bunch is accelerated by wake fields which are due to the hollow beam.

Figure 3 shows an application of the code to a section of the *Wake Field Transformer* . The particle positions of the hollow beam and the central beam are drawn. Further the wake fields generated by the hollow beam, which now accelerate the central beam are shown.

Acknowledgement

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