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WAKE FIELD WORK AT DESY

T. Weiland*
Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, 2000 Hamburg 52, West Germany

Abstract

At DESY, we are investigating the applicability of the "Wake Field Transformer" concept [1] for high gradient acceleration of particles. In this paper we will focus on the experiment which is under construction. We have built a 8 MeV high current linac for generation of a hollow driving beam of 1 μCoulomb charge. The hollow beam gun came into operation in March 1985 and is laser driven with a tungsten (or tantalum) cathode. This new type of gun does not need extremely high vacuum and is very reliable. The linac will come into operation in May. By the end of 1985, we hope to have first results from the Wake Field Transformer operation. All parts including the gun, linac cavities, solenoid coils and the transformer have already been manufactured.

Introduction

The principle of the wake field acceleration mechanism [1,2] has been described in detail in other papers. Thus, we recall only the basics: A driving beam of high charge (1 μC, say) and a test beam of low charge (.01 μC, say) both traverse a special kind of cavity which we call a "Wake Field Transformer". In this cavity the driving beam excites wake fields that lead to deceleration. By proper shaping of the cavity the driving beam excites a wave packet that is subsequently spatially focussed. Thus, there is an increase in field strength proportional to the inverse square root of the volume containing the wake fields. A second pulse of particles entering the transformer through a second pipe and with a suitable delay traverses this concentrated wake field and experiences an acceleration which is much greater than the deceleration of the driving beam. We call the ratio of acceleration to deceleration the "transformation ratio" t. (Values for t of around 10 are expected in our experiment). Thus, one could accelerate a bunch of electrons to 1 TeV using the wake fields of a 100 GeV driving beam and according to our calculations the rate of acceleration will exceed 100 MeV per meter.

This scheme is considered to be a candidate for the next TeV e^+e^- collider since it could be built within a total length of about 10 km if the predicted gradients can be reached.

The Experiment

In order to study the problems associated with the Wake Field Transformer concept, we have proposed an experiment [3] using a complete linac for generating both the driving and the test beam and the transformer. We chose a cylindrically symmetric transformer since it should provide high transformation ratios and since we have better computational tools for such geometries [4] than for the other geometries proposed [1,2].

The driving beam which is hollow has a diameter of 10 cm. When extracted from the gun, the length is 60 cm and the total charge in excess of 1 μC. (Thus, we will have more than 1 kA electron current). We generate the test beam at the same gun and subsequently both are accelerated to about 8 MeV and compressed before entering the wake field transformer.

The overall layout of the experiment is shown in figure 1. The major components of the experiment are listed below.

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* for the Wake Field Accelerator group:
W. Bialowons, H.D. Bremer, F.J. Decker, R. Klatt, H.C. Lewin, G.A. Voss and T. Weiland from DESY
S. Ohsawa from KEK, and S. Wang from Peking

The Gun

We have developed a dedicated laser driven electron gun which provides both the hollow driving beam of high charge and the test beam.

A gun based on electron emission by single photons could not be used in our experiment for the following reasons: such guns need an excellent vacuum ($< 10^{-10}$ mbar) and the photo cathode has to be prepared in situ [5]. In order to avoid both of these difficulties we have chosen a more complex photoemission process, in which the photon energy is much lower than the work function of the cathode material.

With a high enough photon density one obtains a mixture of four effects that taken together make it possible to lift a substantial number of electrons above the potential well:

a) multi photon effect,
b) higher harmonic generation,
c) thermionic supported photo effect,
d) thermionic current.

These effects are illustrated in figures 2 and 3.

A convenient by-product of using a very high power laser is that the cathode surface is cleaned during operation.

Our light source is a commercial Nd-YAG laser consisting of a Q-switched oscillator with an unstable resonator plus an amplifier. The Nd-YAG rod yields infra red light (λ = 1.064 μm) and the laser has a maximum energy of 0.6 J per pulse and a pulse length of 2.5 ns. We do not use a harmonic generator for generation of green and ultra violet light (as was the case at an earlier stage) but allow the harmonic generation to take place at the cathode instead, see figure 2. The laser beam has a "doughnut-like" profile which is suitable for forming a large (10 cm diameter) thin (thickness ≈ 0.5 mm) light ring. Since the original laser beam diameter is about 1 cm, it has been enlarged by a factor of ≈ 10 using a lens and a conical mirror. Figure 4 shows the layout of the gun and figure 5 the calculated equilibrium current distribution [6].

The entire gun is embedded in a solenoidal field of 0.25 Tesla which guides the electrons through the diaphragm of the anode. Such an approach is very different from the conventional one where magnetic fields at the cathode are avoided. Here, a field is necessary for many reasons and in particular it also allows us to use a cathode which is not parallel to the anode and thus to simplify the optics for the laser beam.

So far, we have tested two cathode materials: tantalum and tungsten. The reasons for choosing these were the very high melting point and the ease of machining. It is expected that with this gun we will be able to accelerate 1 μC per pulse and that the modified klystron pulser will enable the dc (pulsed) voltage to reach 150 kV. In order to achieve such high currents we have had to provide a capacitive energy storage device close to the cathode. This consists of a coaxial structure with a length corresponding to half the pulse duration. We began operating the hollow beam gun earlier this year after various tests in 1984 using point-like emitting surfaces.

Using a zinc sulphide screen mounted about 1 meter downstream from the gun (see figure 6) we can see that the tantalum cathode produces a rather homogeneous hollow beam. The pulse (shape and intensity) were investigated with the aid of an insulated end plate which collects all the electrons, with a gap monitor in the circular vacuum pipe and with a current monitor in the high voltage line.

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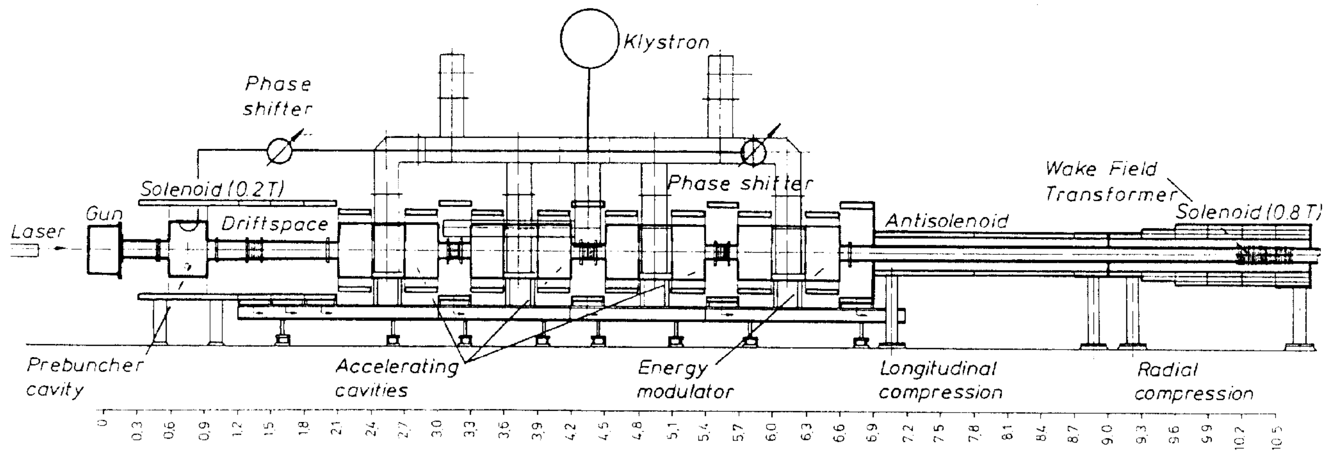

Figure 1: Overall layout of the Wake Field Transformer experiment at DESY.

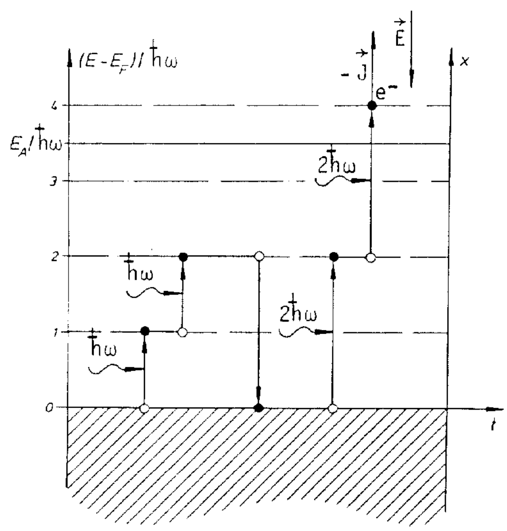

Figure 2: Two(multi)photon effect and second (higher) harmonics generation principle in the cathode illuminated with high density laser light.

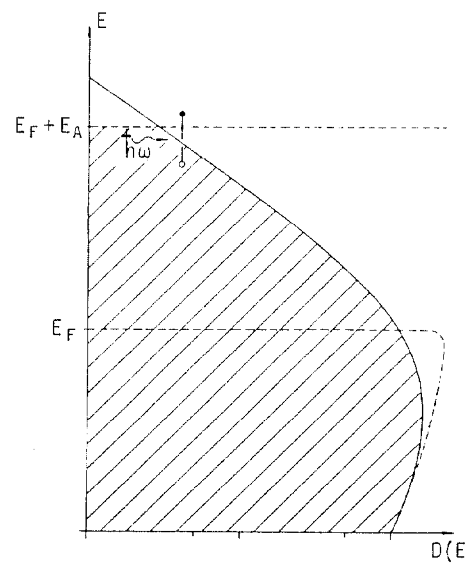

Figure 3: Electron distribution D(E) versus Energy E at low and high temperature showing thermionic emission and thermionic supported photo emission.

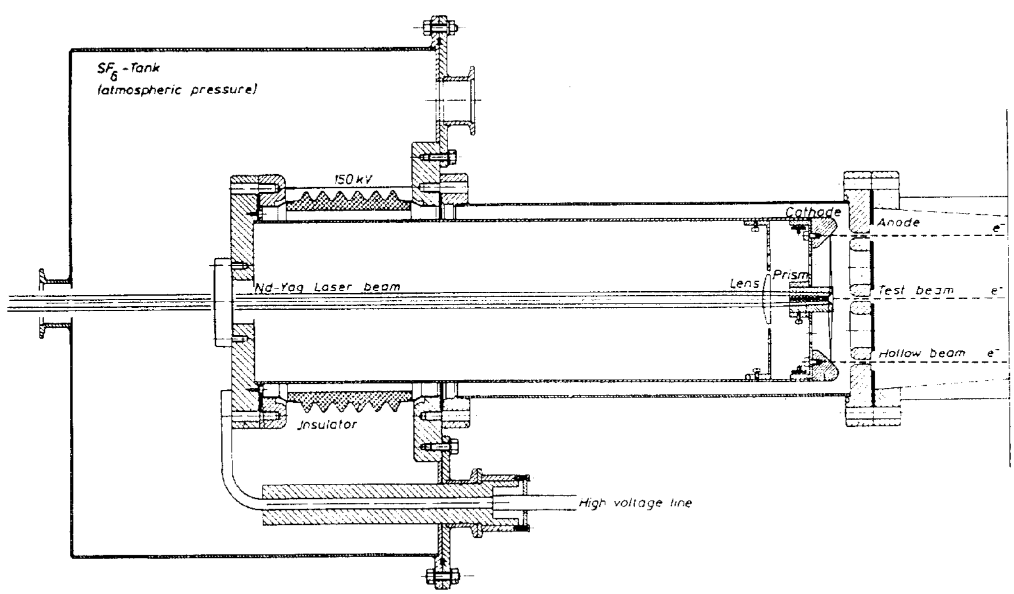

Figure 4: Cross section of the laser driven hollow beam gun.

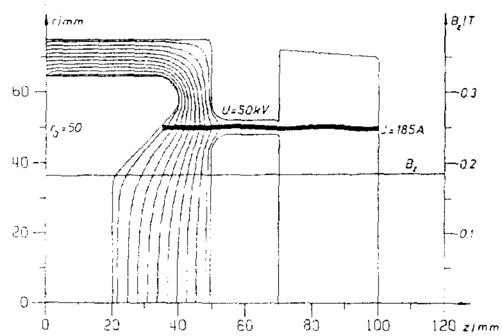

Figure 5: Equilibrium electron trajectories in the hollow beam gun as calculated [6] (using twice the emitting surface as in the real experiment).

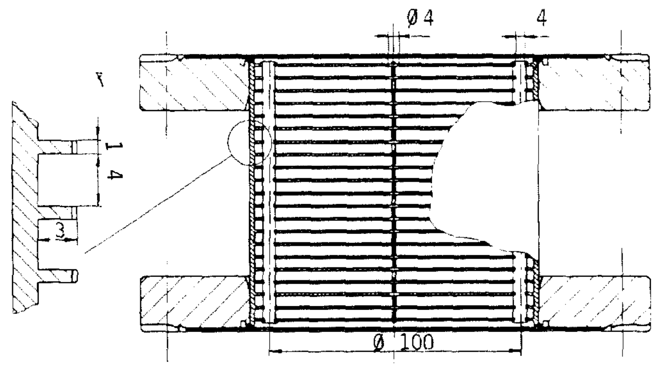

Figure 8: Wake Field Transformer section with 21 cells for a hollow beam of 10 cm diameter.

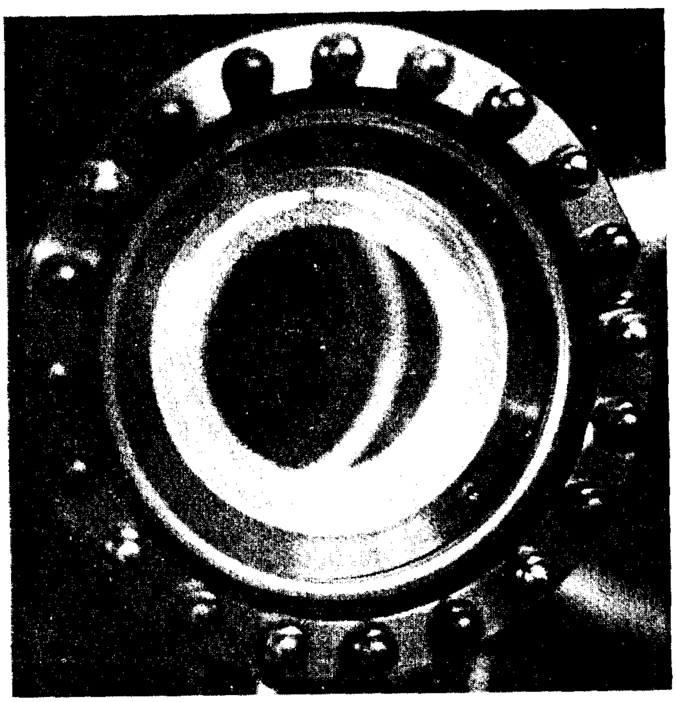

Figure 6: Picture of hollow beam hiding a fluorescent screen showing asymmetries due to cathode imperfections and laser misalignment.

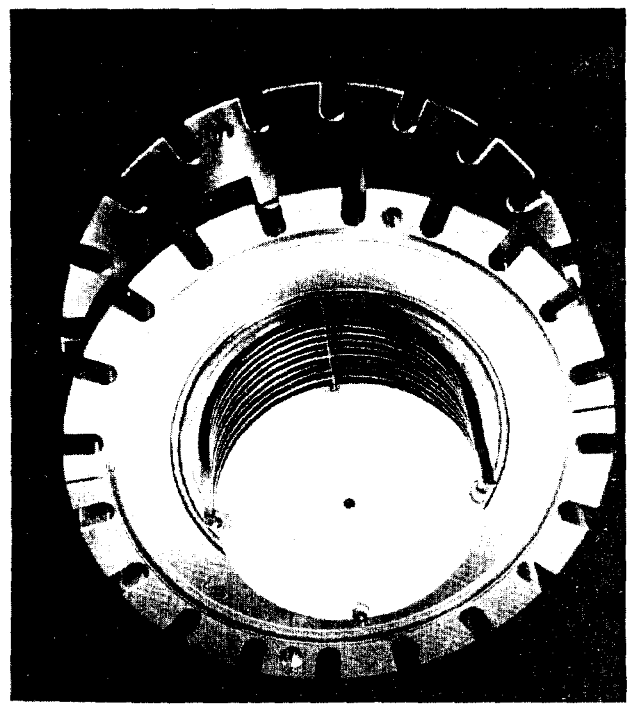

Figure 9: First section of the Wake Field Transformer.

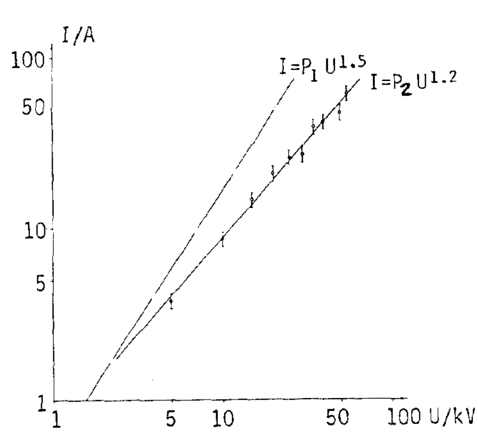

Fig. 7: Measured hollow beam current versus gun voltage showing an exponential dependance of $U^{1.2}$.

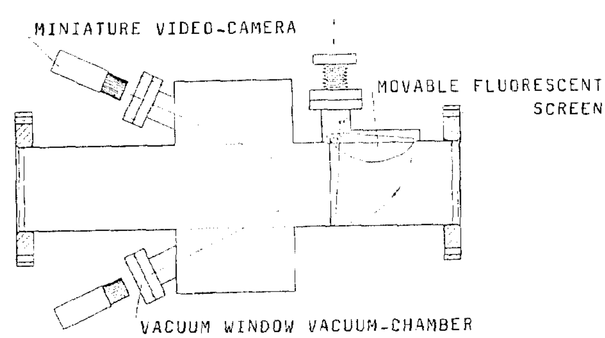

Figure 10: The movable screen monitor for observation of both beams.

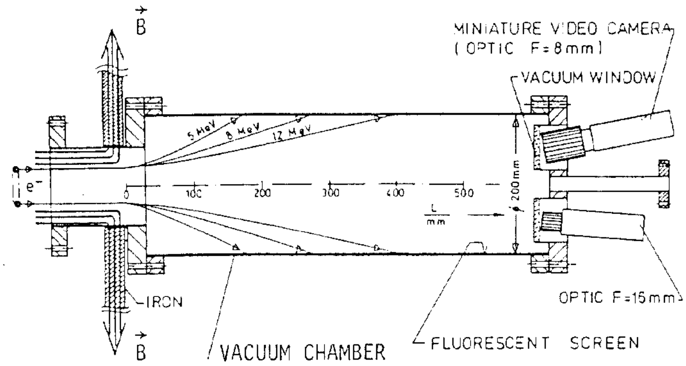

Figure 11: The hollow beam energy spectrometer making use of the solenoid end field.

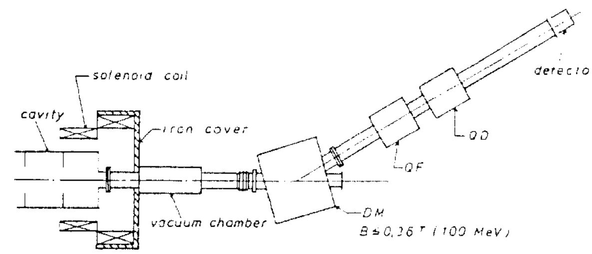

Fig. 12: Layout of the test beam energy spectrometer.

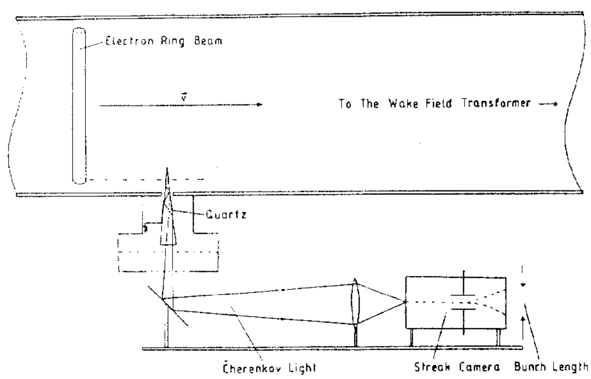

Figure 13: Principle of the Cherenkov light monitor for high resolution beam size measurement of the hollow beam.

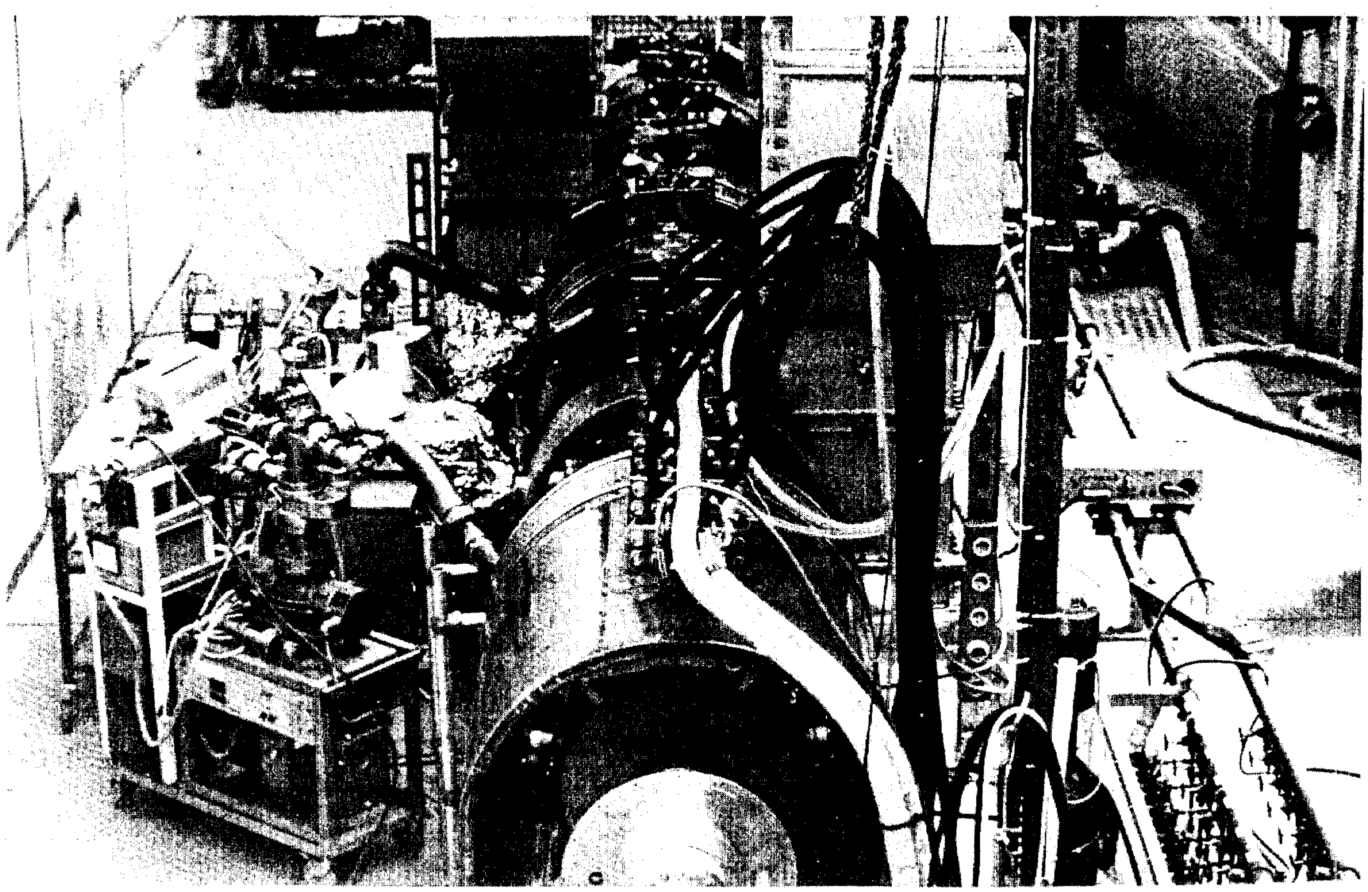

Figure 14: Picture showing the experiment set up (gun and linac).

At first and as expected we found a current of 50 amperes at 50 kV gun voltage and at only 50 % of our maximum laser energy (300 mJoule/pulse). Since the insulating SF_6 tank has not been installed yet, the breakdown limit was reached at 60 kV. Figure 7 shows the measured current versus gun voltage in comparison with theoretical predictions. We do not find the expected $U^{3/2}$ law. This is because not all of the emitting surface is driven in the space charge limited region. This effect should disappear when we use the full laser power. That together with a higher gun voltage should bring us the expected 1 kA beam.

The Linac

The linac consists of a single cell prebuncher cavity (500 MHz, 150 kV) and a chain of four 3-cell cavities (500 MHz) powered by a 1 MW klystron. The zero current energy gain is 8 MeV and the measured shunt impedance is 20 MΩ/m. Solenoid coils surround the cavities whereever possible. All cavities are mounted with a periodicity of $\lambda/2$ and additional phase shifters enable the phases between the prebuncher, the gun pulse and the linac cavities to be controlled. In order to enable a variable energy spread to be produced the last cavity has a separate phase shifter. The overall arrangement is shown in figures 1 and 14.

The High Energy Buncher

After the linac we will install a solenoidal bunching system which will compress the hollow beam longitudinally. Here we make use of a complicated beam dynamics described elsewhere [1,2,7].

The Wake Field Transformer

The Wake Field Transformer comprises four sections, each with 21 transformer cells. The inner disks are supported by four symmetrically arranged metallic bars. This geometry was chosen following an optimizing procedure. The first model built is shown in figures 8 and 9.

The Gap Monitor

For the current measurement of the long pulses a gap monitor which simply interrupts the beam pipe is used. A series of 64 resistors bridges the gap. From these resistors we obtain signals that contain information about the beam distribution, transversely and longitudinally.

The Electron Collector

At the end of the linac or the bunching sections one may mount a collector bridged by a resistor. The integral over the signal indicates the total charge in one pulse.

The Movable Screen Monitor

Between the prebuncher and the linac we will install a fluorescent screen monitor. This complicated device has a flexible screen that can be moved in and out by hydraulics. Two semiconductor cameras bring the pictures to tv screens. Figure 10 shows the layout of this device.

The Fixed Screen Monitor

During the installation, which is proceeding step by step, we are observing the hollow beam using a fluorescent screen. The light is observed by a semiconductor camera. A preliminary picture is given in figure 6. Note that this first result shows the hollow beam after it has passed the buncher section. No bunching voltage was switched on and the dc gun voltage was 50 kV. This picture shows the not perfectly symmetric current distribution due to laser misalignment. This currently is being improved.

The Hollow Beam Spectrometer

In order to analyse the energy distribution in the driving beam we constructed a spectrometer as sketched in figure 11. As the particles leave the solenoid and enter the field free region they are kicked by the radial end field. The path of a particle then depends on its energy and they will hit a surrounding beam pipe at different longitudinal positions. The inside of the chamber has a fluorescent coating and electrons are observed by two tv cameras viewing from the end of the chamber.

The Central Beam Spectrometer

For energy analysis of the central beam we used a standard set-up with a dipole, two quadrupoles and counters as shown in figure 12.

The Cherenkov Light Monitor

For short pulse measurement we intend to use Cherenkov light generated when electrons of the driving beam penetrate some glass wedges. The light pulse is then recorded by a commercial streak camera. The layout of this device is shown in figure 13.

Summary

The Wake Field Transformer experiment at DESY has just been assembled. First tests show that the hollow beam gun based on a complex photo emission process behaves reliably and at a moderate vacuum pressure yields a current in agreement with our expectation, so that we obtained about 50 A (or a total charge of 150 nC) at 50 kV (30 % of design voltage) and a laser power of 50 MW (50 % of maximum power) without fine tuning of the laser optics. Higher laser power and voltage will increase this current towards the design current of 1 kA. The linac is just coming into operation. The first accelerated hollow beam may be obtained soon. We hope to have the first Wake Field Transformer results by the end of this year.

Acknowledgement

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