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FIRST RESULTS OF KEK PLASMA WAKEFIELD ACCELERATOR EXPERIMENT

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Abstract A plasma wakefield experiment has started using a high intensity 250MeV electron beam, which is separated into 5 or 6 bunches by the rf field. The preceding bunches generate the wakefield in a plasma to accelerate or decelerate the following bunches. It is observed that a plasma, 1m in length with density of $4 \times 10^{11}\mathrm{cm}^{-3}$, caused approximately 4MeV energy shift in the fifth bunch.

INTRODUCTION

The plasma wakefield accelerator (PWFA)[1] has been the recent subject of both theoretical and experimental investigation. Besides the high acceleration gradient, this acceleration scheme has several advantages over other plasma acceleration schemes. They include no use of laser, insensitiveness to phase slippage from the plasma wave, transverse focusing effect, etc.. We report here a testing of the PWFA scheme where the beam energies of both the driving and trailing bunches are scaled up to ultrarelativistic region from the hitherto experiments.[2] Another feature of the present experiment is the use of a sequence of bunches, where a bunch can be a driver and a witness at the same time. Build-up of the wakefield is expected in the optimum conditions.

The experimental setups have been already described in the previous paper,[3] but we repeat some description in the next section to make the present paper self-consistent. We then compare our experimental results to the calculation. The last section contains conclusion and discussion.

EXPERIMENTAL SETUPS

We use the large current electron linac for the positron production in the KEK photon factory.[4] In usual operations, large current electrons bombard a target to generate positrons. In the PWFA experiments, the target is removed so that the electrons go directly through a plasma chamber. The electrons are then horizontally diverged by an energy analyser which gives $\pi/3$ deflection to the central energy component. A streak camera measures the horizontal distribution of each bunch which gives the energy spectrum. Usually the beam has 6 bunches.

The maximum beam energy is 250MeV. It is observed without the plasma that the preceding bunches have higher central energy than the following bunches. The central energies of 6 bunches span about 20MeV. In addition, each bunch has energy distribution with 2-5MeV rms deviation. These energy distributions are caused by the wakefield in the vaccum duct, 80m long from the source to the plasma.

The bunch separation is 10.5cm or 350psec, inverse of the rf frequency, 2856MHz. The total charge in 6 bunches is 5-10nC. The transverse rms radius of a bunch measured by a fluorescent screen is 1-1.5mm and the longitudinal rms bunch length measured by a streak camera is 10psec.

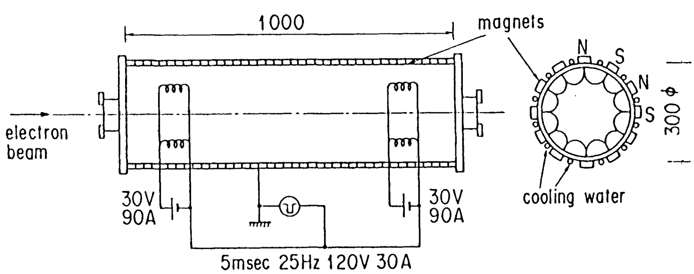

FIGURE 1 Plasma chamber.

The plasma is contained in a chamber of Figure 1, 300mm in diameter and 1000mm in length. An argon plasma is produced by pulse discharges between multifilaments and the chamber. The pulse has discharge voltages 100-130V, currents 20-30A, a duration of 2msec and a rate of 1Hz, which equals the beam rate of the linac. The multidipole field of permanent magnets, 1kG at the inner surface of the chamber, confines the plasma. The chamber is water-cooled. The vacuum system is independent of the linac, using 50μm thick titanium foils at the inlet and outlet of the beam. The identical foils are used also at the outlet of the linac duct, and at the inlet and the outlet of the energy analyser.

The electron density and temperature are measured by a Langmuir probe. The plasma is measured to be radially homogenious, extending over 200mm. Though we have no measure to know the longitudinal distribution, we suppose that it is fairly homogenious also in this direction, guessing from the measurement made on a similar confinement device.[5] The electron density is controlled both by the gas pressure and by the discharge current. Typical plasma parameters are a maximum electron density $1 \times 10^{12}\mathrm{cm}^{-3}$, an electron temperature 2-3eV, and a neutral gas pressure of 4×10^{-4}torr under a base pressure of 1×10^{-7}torr.

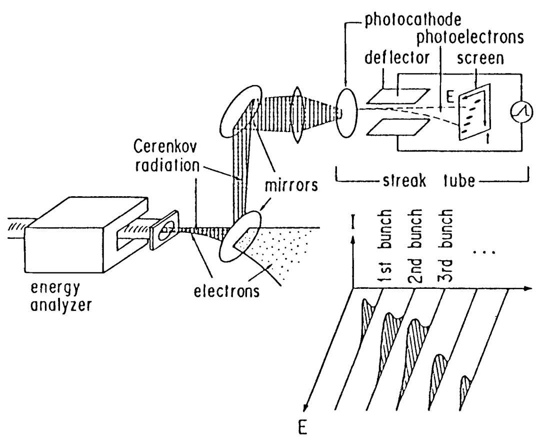

FIGURE 2 Bunch energy measurement using a streak camera.

Combination of the energy analyzer and the streak camera enables the bunch energy measurement, as shown in Figure 2. The bunches fly in the air for about 1000mm behind the energy analyzer to produce Cerenkov radiation. The radiation is reflected by mirrors and introduced into the streak camera. The first mirror with 150mm diameter accepts 8% energy dispersion, so it is still necessary to sweep the analyser current to obtain the spectra of all bunches. The lens focuses the first mirror position onto the slit of the streak camera and a Dove prism rotates the image so that the energy deflection is perpendicular to the time axis of the camera. The streak picture is two dimensional; one dimension for horizontal positions of particles which gives convolution of the bunch energy and the horizontal bunch size, the other dimension for time to identify the bunches. The picture intensity gives the number of particles. Each streak picture is digitized and total count, mean and standard deviation are calculated.

RESULTS AND ANALYSIS OF EXPERIMENT

Before going to the experimental results, let us examine the computed results based on the linear two-dimensional model.[6] Figure 3 gives the calculated field gradient felt by bunches as a function of the plasma density. Each bunch is assumed to have parabolic distribution 1.4mm in radius in transverse direction and σ = 10psec Gaussian distribution in longitudinal direction. Another assumption is that the total charge of 7nC is Gaussian-distributed in 6 bunches.

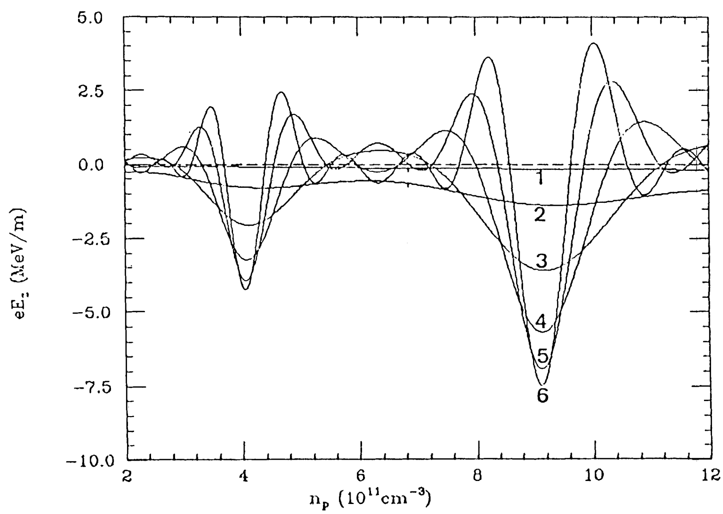

FIGURE 3 Accelerating gradients received by bunches as a function of the electron density. The numerals denote the order of bunches.

Though we can see only two resonances in the figure, a resonance occurs whenever the relation $kf = \nu$ is satisfied, where f is the rf frequency, ν is the plasma frequency and k is an integer, which corresponds to the electron density $n_e = 10^{11}k^2$ in the parameters of our experiment. In a resonance, all bunches are decelerated. Among resonances, there exist density regions where some bunches are accelerated and some are decelerated. It is fatally impossible to accelerate all bunches, because the driving bunches have to be decelerated to accelerate the trailing bunches.

Experimentally, we have measured the energy spectra of the 4th and 5th bunches as a function of the plasma density. Figure 4 gives a result, where plotted points give means of the energy distribution in bunches. We see the resonance around the plasma density of $4.0 \times 10^{11}\mathrm{cm}^{-3}$, where $k = 2$, or the relation $2f = \nu$ is satisfied. Approximately 4MeV deceleration is observed at the resonance and about the same amount of acceleration is observed at the density nearby the resonance. The lines are calculated energy shift reproduced from Figure 3. It takes about 10min to get a sequence of data, while energy shift without the plasma stays within ±1MeV in 30min run.

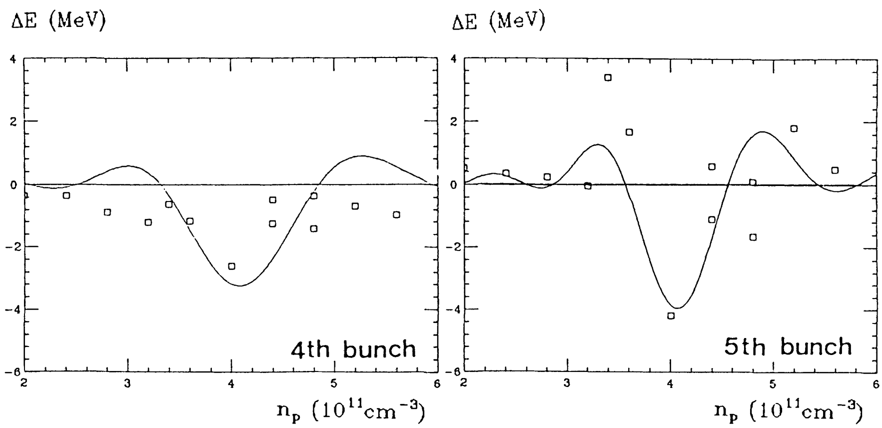

FIGURE 4 Observed energy shift dependence on the plasma density at 4th and 5th bunches.

The fact is that the resonant density observed by the probe in our experiment was $4.8 \times 10^{11}\mathrm{cm}^{-3}$. Because our plasma density measurement by a Langumuir probe has an error of approximately 20%, we fit here the observed resonant density to the calculated value.

CONCLUSION AND DISCUSSION

We have observed approximately 4MeV energy shift caused by the wakefield in the plasma column 1m in length. This value is consistent with the calculation based on the linear model.

Because our experiment has just begun, many are left to be examined. The higher density both in the plasma and the beam will bring the higher energy shift. Accurate density measurement using interferometric method is essential. Focusing/defocusing effect of the plasma is certainly another interesting subject. However, the transverse beam broadening caused by the multiple scattering at the titanium windows makes this study impossible in the present setup.

Our experiments using the positron linac have further possibilities. One is the use of a positron bunch as a witness. Because the decelleration field for electrons is felt as the acceleration field by positrons, whole the built-up field can be used to accelerate them. Another is the modification of the envelope of the bunch sequence. It is well known that the longitudinal shape of the driving bunch affects the transformer ratio.[7] We can expect the same effect by shaping the envelope.[8]

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