STATUS OF DIELECTRIC-LINED TWO-CHANNEL RECTANGULAR HIGH TRANSFORMER RATIO ACCELERATOR STRUCTURE EXPERIMENT *

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Abstract

Recent tests of a two-channel rectangular dielectric lined accelerator structure are described; comparison with theory and related issues are presented. The structure (with channel width ratio 6:1) is designed to have a maximum transformer ratio (TR) of ~12.5:1. It operates mainly in the LSM31 mode (~ 30GHz). The dielectric liner is cordierite (dielectric constant ~4.76). The acceleration gradient is 1.2 MV/m for each 10nC of the drive bunch for the first acceleration peak of the wakefield. The structure is installed into the AWA beam-line (Argonne National Lab) and is excited by a single 10-50nC, 14MeV drive bunch. Both the drive bunch and a delayed witness bunch are produced at the same photocathode. This is the first experiment to test a two-channel dielectric rectangular wakefield device where the accelerated bunch may be continuously energized by the drive bunch. The immediate experimental objective is to observe the energy gain and spread, and thereby draw conclusions from the experimental results and the theory model predictions. The observed energy change and transverse kick of the test bunch are well explained [1].

INTRODUCTION

Two-channel structures [here and below we are discussing dielectric-lined waveguides because they are the simplest to manufacture] can deliver a high TR without the need to impose any complex set of requirements on the drive bunch or bunch train such as needed by single channel devices [2-4]. The two-channel configuration can have its geometry tailored to redistribute the wakefields in such a way that the acceleration gradient in one of the channels (referred to as the test or acceleration channel) is much higher than the deceleration gradient in the other (referred to as the drive channel) [5-7].

In here we are describing a two-channel 10cm long rectangular device with TR as high as ~12:1. The drive channel [6 mm × 12 mm] will accommodate the available drive bunch produced at AWA. The time-delayed test bunch is to be accelerated in a narrow test channel [2mm × 12mm], and is produced off-axis on the same photocathode where the drive bunch is produced. The position and focusing of the test bunch are determined by the same controls that focus the drive bunch [8]. Given narrow size of the test channel preceded by a mask to collimate the beams, the transmission of the test bunch requires both accurate positioning and having a correct angle. Under these circumstances it was found that the test bunch can be transmitted only when the drive bunch is under-focused resulting in low drive changes not exceeding 15nC. In addition the separation between bunches was measured to be typically 7mm, meaning the drive bunch was typically off the channel center by 2–3 mm.

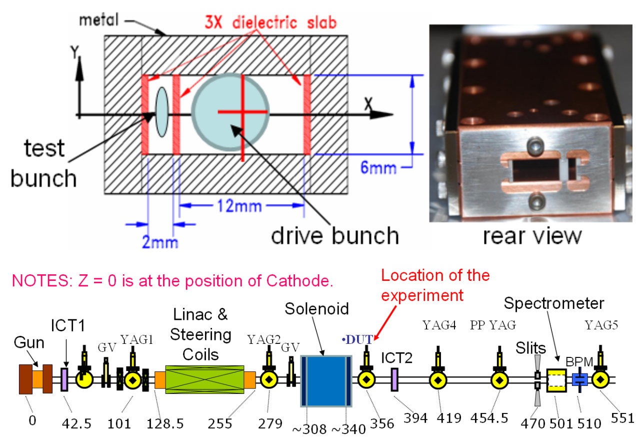

Figure 1: (Top, left) Cross-section of the apparatus (dielectric slab thickness – from left to right – is 1.26, 2.03 and 1.06 mm); and (bottom) its position in the AWA beam line.

These practical difficulties indicate that two-bunch schemes are better tested if a facility is equipped with two guns, and two separate beam lines to produce and manipulate the beams independently.

However, the aforementioned obstacles did not prevent obtaining successful data sets.

EXPERIMENTAL RESULTS

Data were collected for three different delays between the drive bunch and the test bunch, namely ~6mm, ~11, and ~22 mm. For each delay multiple shots were recorded on the spectrometer screen; the typical information is the energy gain/ loss received by electrons and the horizontal kick received by electrons; the first one is read by making

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vertical projections of the image on the screen, the second one is read by making horizontal projections on the screen. The energy slit helps to narrow down the energy value; being positioned horizontally, the energy slit, however, does not affect the readouts to infer the horizontal deflection of the bunch, which is later processed to obtain the value of the horizontal deflecting force responsible for the bunch deflection [9].

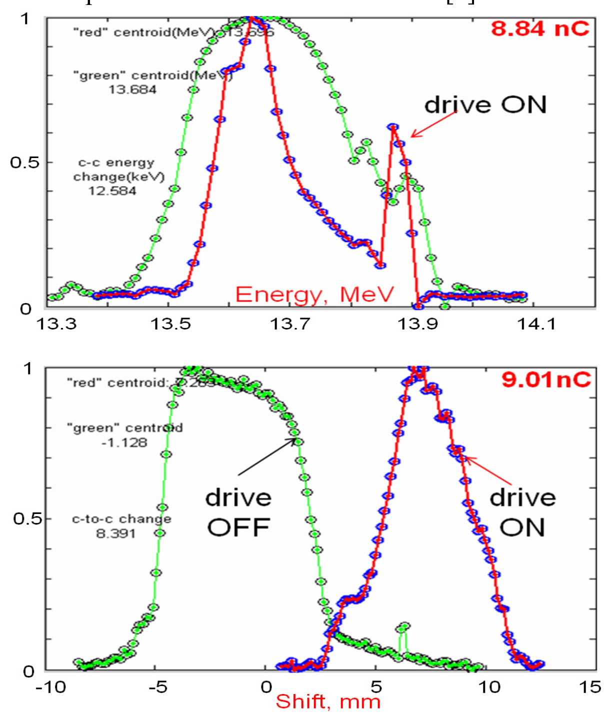

Figure 2: Typical energy distribution, and bunch horizontal distribution (observed in 80-85% of shots) when the delay was ~6mm; the distributions are normalized to 1.

With the delay ~6 mm [see Fig. 2], the typical energy loss was up to 50–100keV and the energy gain was up to 90–100keV; in average the energy changed by ~0keV. The horizontal kick that led to the shift as shown in Fig. 2 was about 6.18–6.8 mrad.

With the delay ~11 mm [Fig. 3], the jitter of 50–60keV; and the energy slit error 77keV required some corrections. Taking these into account, the energy loss was up to 65keV, while the energy gain was in the range 65–150keV; the average energy change was ~50keV. The horizontal kick that led to the typical shifts presented in Fig. 3 was ranging from –2.45 to –5.2 mrad; in average it was -3.9 mrad.

With the delay ~22mm [Fig. 4], the jitter of 40–50keV and the energy slit error 77–154keV required some corrections. The energy gain was up to 350keV; the average energy change was ~ 170–220keV, and the horizontal kick was inferred to be about +12.2 mrad.

When the aforementioned values are re-calculated to 50nC of the drive charge and normalized per 1m, an excellent agreement can be found between the theory and measurements [see Figs. 5-7].

Figure 5 shows that with the delay ~6mm, to have the observed energy loss the accelerating force Fz (re-computed for 50nC of the drive charge) must be up to –4.95/–5.5MeV/m; to have the observed gain, Fz must be up to +2.75 / 5.5 MeV/m.

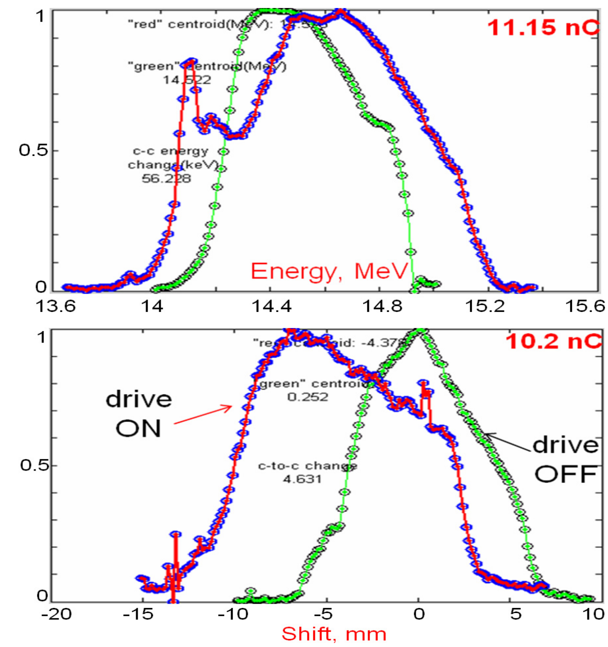

Figure 3: Typical energy distribution, and bunch horizontal distribution (observed in 80% of shots) when the delay was ~11mm; distributions are normalized to 1.

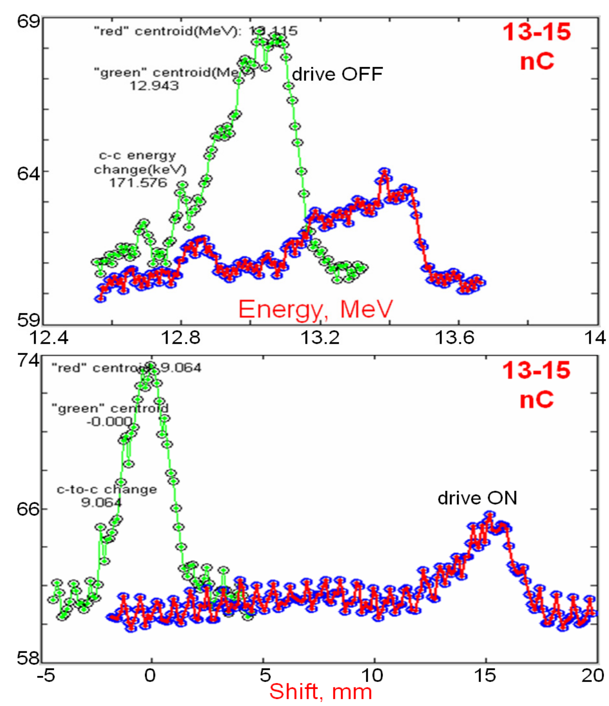

Figure 4: Typical energy distribution, and bunch horizontal distribution (observed in 80% of shots) when the delay was ~22mm; note that these are examples of non-normalized distributions.

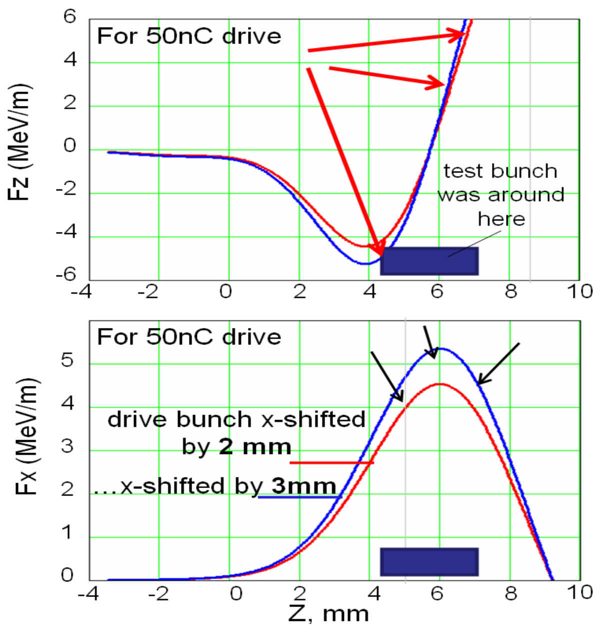

Figure 5: (See text; simulations of Fz/ Fx here and in Figs. 6 and 7 are done by CST Microwave Studio for the test channel.)

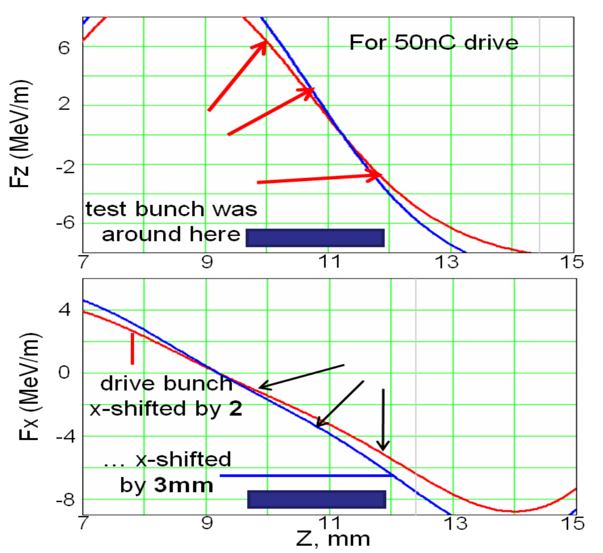

Figure 6: (See text, and the caption to Fig. 5.)

At the same time, to have the measured horizontal kicks the horizontal deflection force Fx (re-computed for 50nC of the drive charge) must be about 4.65/5.12 MeV/m. All these values (pointed at by red or black arrows) can be found on the Fz(Z)/ Fx(Z) curves when the drive bunch is x-shifted from the apparatus centre by 2–3mm as observed in the experiment.

Figure 6 presents the similar comparison for the delay ~11mm. To have loss, Fz (re-computed for a 50nC drive bunch) must be up to –2.85 MeV/m; to have observed gains, Fz must be between +2.85/6.7 MeV/m; to have x-kicks Fx (re-computed for a 50nC drive bunch) must range between –1.72 and –3.6 MeV/m, and be in average –2.8 MeV/m. Again, all these values (pointed at by the arrows) can be found on the Fz(Z)/ Fx(Z) curves just exactly where the test bunch was.

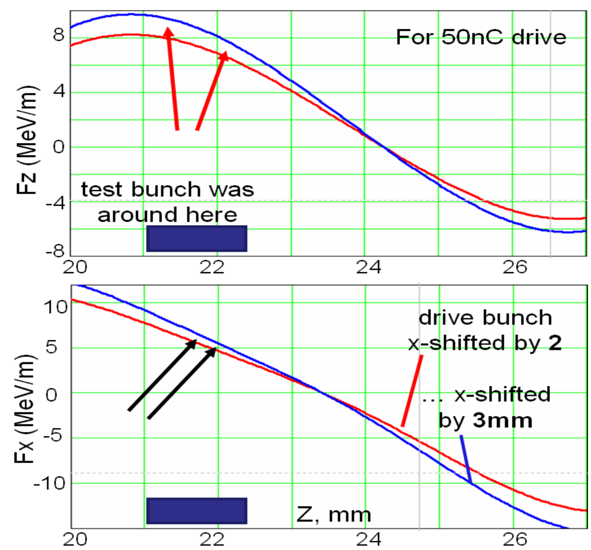

Figure 7: (See text, and the caption to Fig. 5.)

Figure 7 is for the delay of ~22mm. To have observed gains, Fz must be up to +9 MeV/m, but in average 6.5–8.5MeV/m; to have x-kicks Fx must be about 5.4–6.1 MeV/m. Again, Fz/ Fx are re-computed for a 50nC drive bunch, and all the values are found on the the Fz(Z)/ Fx(Z) curves just exactly where the test bunch was.

In summary, the theory model predictions are well confirmed by the experimental data.

Considering Fig. 6, one may notice that moving a narrower bunch to a delay of 9mm would secure both high acceleration and low deflection. However in general, the deflection in a rectangular configuration is an intrinsic feature. An exceedingly far better choice for accelerator applications is a coaxial-like geometry where symmetry cures the unwanted deflection [7]. Still, the rectangular version makes a simple example suited well enough for a proof-of-principle experiment.

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