Transformer Ratio Enhancement Using A Ramped Bunch Train In A Collinear Wakefield Accelerator

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Abstract. We present a practical method for achieving a transformer ratio (R) greater than 2 with any collinear wakefield accelerator – i.e. with either plasma or structure based wakefield accelerators. It is known that the transformer ratio cannot generally be greater than 2 for a symmetric drive bunch in a collinear wakefield accelerator. However, using a ramped bunch train (RBT) where a train of n electron drive bunches, with increasing ('ramping') charge, one can achieve $R = 2n$ after the bunch train. We believe this method is feasible from an engineering standpoint using existing technology and an experiment to be preformed at the Argonne Wakefield Accelerator (AWA) is planned.

INTRODUCTION

In general, the wakefield theorem [1] restricts the maximum accelerating field behind the drive bunch in a wakefield accelerator to be less than twice the maximum retarding field inside the drive bunch thus limiting the efficiency which can be obtained. One of the concepts central to the physics of wakefield acceleration is the transformer ratio, R, defined as R = (Maximum energy gain behind the bunch)/(Maximum energy loss inside the drive bunch). For the case of a collinear drive and witness beam geometry device, R is less than 2 except in a few special cases. For the purposes of this paper we only consider one regime where the wakefield theorem does not apply, namely, the use of an axially asymmetric charge distribution in the drive bunch. We can understand the RBT method by invoking linear superposition and expansion of $W(z)$, into the normal modes of the accelerator - i.e. $W(z) = \sum_l W_l \cos(k_l z)$

Several schemes have been proposed to obtain $R > 2$ in collinear wakefield accelerators, but no experimental results have been obtained due to the inherent difficulties of these experiments. One of the more promising schemes [2] sends a single drive bunch, with an asymmetric axial current distribution (Fig. 1a) through a collinear wakefield accelerator. Simulations show that R can be much greater than 2 for the triangular (ramped) bunch distribution as seen in the figure. Notice that most of the particles in the drive bunch experience the same decelerating wakefield, W^-, but the accelerating wakefield behind the bunch, W^+, is much larger. Using a similar idea, a second scheme tailors the profile of a train of drive bunches [3] into a triangular

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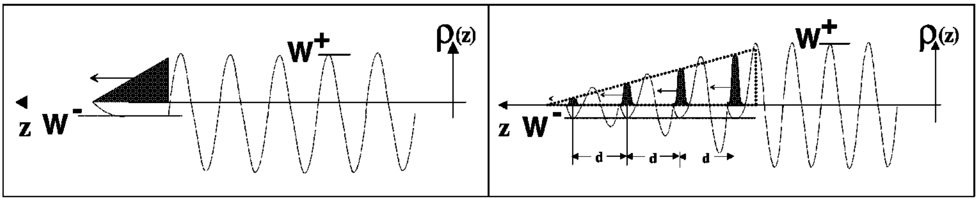
ramp (see dotted line in Fig. 1b) to produce R >2. In this later scheme, the individual bunches in the train are symmetric (e.g. gaussian) separated by a distance d. The charge is then ramped up such that the first bunch in the train has the lowest charge and the last bunch the highest. From the figure we see that all four drive bunches in the drive train experience the same maximum decelerating field W^- just like in the case of a single triangular ramped bunch. Thus, the fundamental condition for both of these schemes is that the trailing particles (bunches) in the drive bunch (train) are positioned in the accelerating phase of the leading particles (bunches) so that all the driving particles experience the same maximum decelerating field.



(a) (b)

FIGURE 1. Two schemes that have been proposed to generate $R = W^+/W^- >> 2$. The height of the shaded area, $\rho(z)$, represents the total amount of charge in the bunch at location z while the solid, sine-like, line is the amplitude of the wakefield driven by the beam. (a) A single drive bunch with a triangular axial current distribution moving to the left. (b) A train of gaussian drive bunches with an overall triangular pattern of the train (see dotted line) moving to the left.

The difficulty with the schemes that propose to use asymmetric axial current distribution to achieve $R > 2$, arises from the lack of suitable techniques to tailor the axial distribution of the drive beam. For example, for nearly 10 years it has been known that beam dynamics codes (such as PARMELA) predict improved beam quality from rf photoinjectors when driven by a 'flat top' axial current distribution. Despite this knowledge, no one has successfully produced a 'flat top' although several experimenters are getting close. Since the 'flat top' pulse is most likely easier to generate than the 'triangular top' pulse it may be some time before this method is used to obtain $R > 2$.

In this paper we consider the later method, here termed, the 'ramped' bunch train (RBT) method of transformer ratio enhancement. Since the AWA facility has already generated a 'flat' bunch train [4] it should be easy to generate a RBT. How the RBT is generated and the difficulties we are likely to encounter will be discussed in a later section.

We begin by reviewing the concept of transformer ratio for a single, symmetric beam in a collinear wakefield accelerator and studying the trade off between the acceleration gradient and the transformer ratio. We then examine the ramped bunch train method and present an algorithm for choosing the spacing of the bunch and charge of the different bunches in the train. Finally, we describe a proof of principle experiment where we propose to send a train of 4 electron bunches, with a ramped charge distribution through a dielectric lined waveguide.

TRANSFORMER RATIO AND ACCELERATION GRADIENT FOR A SINGLE BUNCH

In this section we examine the dependence of the transformer ratio (R_0) and the peak acceleration gradient (W^+) of a single bunch - where the subscript '0' denotes a single bunch. As will be seen in the next section, the transformer ratio enhancement of the ramped bunch train is maximum when $R_0 = 2$.

Numerical simulations of a single drive bunch passing through a collinear wakefield accelerator are presented. The particular collinear accelerator we use for our simulations is a dielectric lined cylindrical structure with inner radius a, outer radius b and dielectric constant ε as shown in Fig. 2. Although we use a dielectric wakefield accelerator (DWFA) for analysis the results we derive in this section are general to dielectric structures, metallic structures, and plasmas. In the last section of this paper we propose an experiment for using a RBT to drive both a DWFA and a plasma wakefield accelerator (PWFA).

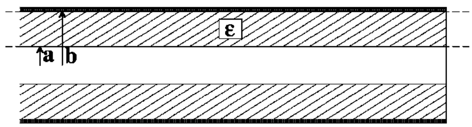


FIGURE 2. The dielectric wakefield accelerator. A hollow dielectric (ε) cylinder of inner radius a and outer radius b covered by a copper jacket. The drive bunch passes through the vacuum hole of radius a.

Using the analytic theory of Rosing and Gai [5] we numerically simulate the longitudinal wakefield in a dielectric structure excited by an axial current distribution. We consider a dielectric structure of inner radius a = 2.5 mm, b = 2.8 mm, dielectric constant ε = 38 excited by a single drive bunch with a gaussian axial current distribution of width σ= 1.5 mm. From the simulation results (plotted in Fig. 3) we obtain the wavelength of the fundamental accelerating mode (λ_0 = 7.89 mm) the maximum value of the accelerating field behind the bunch (W^+ = 0.54 MeV/m/nC) and the minimum value of the decelerating field within the bunch (W^- = 0.28 MeV/m/nC). From this we calculate $R_0 = W^+/W^- = 1.9$ for a normalized bunch length of $\sigma/\lambda = 0.19$.

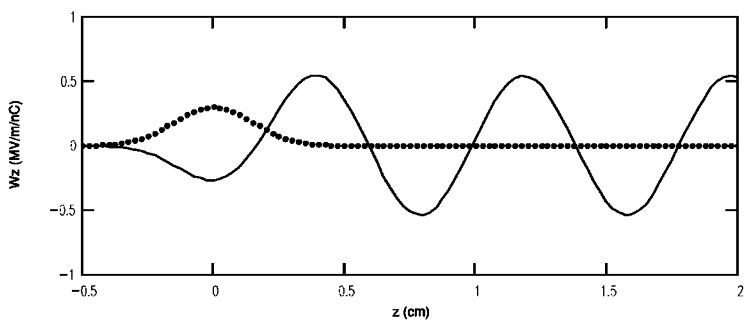


FIGURE 3. Longitudinal wakefield (solid line) excited by a gaussian bunch (dotted line) with Q = 1 nC and σ= 1.5 mm. The fundamental wavelength λ_0= 7.89 mm.

In general, the transformer ratio, R_0, and the peak acceleration gradient behind the bunch, W^+, are functions of the normalized bunch length (σ/λ). Keeping the dielectric structure fixed, thus fixing λ, we can vary σ in our simulations. We now plot the dependence of R_0 and normalized W^+ as a function of the normalized bunch length, σ/λ, in Fig. 4. (W^+ has been normalized to W^+,max - the maximum peak acceleration gradient for a given bunch length σ.)

As one would expect, the simulations (plotted in Fig. 4) show that the peak acceleration gradient W^+ increases as the bunch length decreases. A detailed study shows that the maximum value of the peak acceleration gradient, W^+, max is obtained for values of $\sigma = \lambda/100$ and below. This means that once the bunch length is below $\lambda/100$ no appreciable increases to W^+ occur.

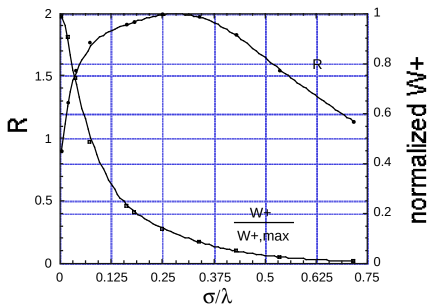


FIGURE 4. Transformer ratio, R, and peak accelerating field, W^+ as a function of the normalized bunch length.

The behavior of R_0 as a function of σ/λ is more complicated than the monotonically decreasing behavior of W^+. From Fig. 4 we see that R_0 is peaked near bunch length $\lambda/4$, while dropping off towards one for bunch lengths either side of $\lambda/4$. (As an aside, it is well known that the transformer ratio is equal to 2 for a delta function even though the asymptotic value for Fig. 4 is 0.75. This isn't surprising since the function R is simply discontinuous for zero bunch length - i.e. a delta function.)

We now see that there is a tradeoff between R_0 and gradient W^+. Maximum gradient is obtained by driving the collinear accelerator with a very short bunch while maximum transformer ratio is obtained when $\sigma=\lambda/4$. The optimal point of operation is arguably near $\lambda/20$, but since we are interested in maximizing the transformer ratio, we choose σ near $\lambda/4$, so that $R_0 = 2$.

ENHANCED TRANSFOMER RATIO WITH A RAMPED BUNCH TRAIN

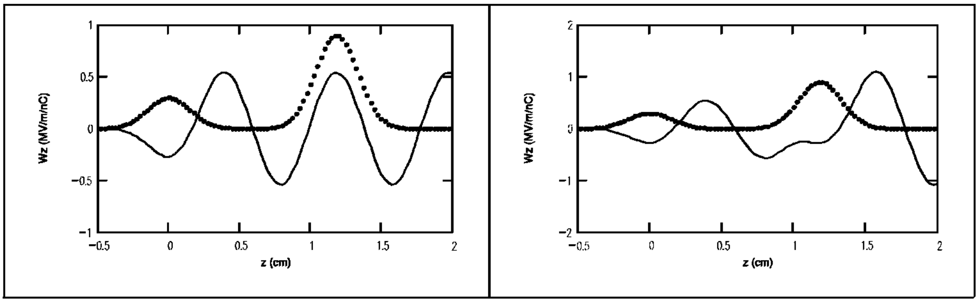
In this section we describe a method [3] for enhancing R beyond 2 in a collinear wakefield accelerator. We call this the ramped bunch train (RBT) method and show that it works by simple linear superposition of the fields from a train of drive bunches using a clever arrangement of drive bunch spacing and charge. In addition to the work of [3] we add a new condition for enhancing R - the symmetric, single wake.

Flat Bunch Train Wakefields

In the typical 'flat' bunch train experiments, such as those at CLIC and AWA a train of equal intensity bunches ($Q_0 = Q_1 = ...$), separated by one fundamental wavelength ($d = \lambda_0$) is used to drive the collinear wakefield accelerator. This separation of $d = \lambda_0$ means that the second bunch is placed in the deceleration phase of the first bunch so that the self-wake of the second bunch and the decelerating field left behind by the first bunch reinforce each other. Consider the example of a two bunch, 'flat' bunch train. Using the single bunch wakefield (charge $Q_0 = 1$ nC) of Fig. 3, we calculate the net wakefield generated by both the single bunch and a second bunch, of equal charge ($Q_1 = 1$ nC) located at $d = \lambda_0 = 7.89\ mm$. Since the single (first, n=0) bunch of the above example had $W_0^+ = 0.54$ MeV/m/nC and $W_0^- = 0.28$ MeV/m/nC, by linear superposition, we obviously have the peak 'net' wakefield left behind the second (n=1) bunch, $W_{1,\ net}^+ = W_0^+ + W_1^+ = 2W_0^+ = 1.08$ MeV/m/nC and 'net' minimum decelerating field within the bunch train, $W_{1,\ net}^- = W_0^+ + W_1^- = 3W_0^- = 0.84$ MeV/m/nC, located within the second bunch. Thus our peak acceleration gradient has doubled, but our minimum decelerating field within bunch has tripled resulting in a 2/3 reduction in the transformer ratio to 1.3. In general, for a flat bunch train, the net fields after the n^{th} bunch are $W_{n,\ net}^+ = (n+1)W_0^+$ and $W_{n,\ net}^- = W_0^- + nW_0^+ =$ and thus $\boldsymbol{R_n} = (n+1)/(n+1/R)$ which goes to $\boldsymbol{R_n} = 1$ for large n.

Ramped Bunch Train Wakefields

In the RBT method the second bunch is placed in the accelerating phase of the first bunch (Fig. 5) or at distance $d = 1.5\lambda_0$. The effect of this is to cancel out some of the self-wakefield of the second bunch with the accelerating field of the first bunch so that the second bunch experiences a reduced deceleration. With the second bunch located at the accelerating phase of the first bunch, the charge of the second bunch (Q_1) is increased until the decelerating field it experiences is equal to that of the first bunch (i.e. W_0^-). For example, let the first (n=0) bunch have charge Q_0 and produce wakefields W_0^- and W_0^+ such that $W_0^+ = R_0\ W_0^-$. If the second (n=1) bunch is located at $d = 1.5\lambda_0$ and has charge $Q_1 = kQ_0$, then the net decelerating field it experiences ($W_{1,\ net}^-$) is the sum of the accelerating field of the first bunch (W_0^+) minus its self-wake ($W_1^- = kW_0^-$) or $W_{1,\ net}^- = (R_0\text{-}k)W_0^-$. Now, if $W_{1,\ net}^-$ is to be equal to W_0^- then we must have $(R_0\text{-}k)\ W_0^- = -W_0^-$. *or* $k = R_0 + 1$. If $R_0 = 2$ then $k=3$ and we have $Q_1 = 3Q_0$ and $W_1^+ = 3W_0^+$. To calculate the 'net' peak accelerating field left behind the second bunch we simply subtract the wakefield produced by the first bunch (W_0^+) of charge Q_0 and from the wakefield produced by the second bunch ($W_1^+ = 3W_0^+$) of charge $3Q_0$ and we have $W_{1,\ net}^+ = 3W_0^+ - W_0^+ = 2W_0^+$. Finally, we can *calculate* $R_1 = W_{1,\ net}^+ / W_{1,\ net}^- = 2W_0^+ / W_0^- = 2\ R_0$.



(a) (b)

FIGURE 5. A 'two-bunch' train. (a) The location and relative magnitude of the 2nd bunch (dotted line) is shown relative to the location of the first bunch (dotted line) and its wake (solid line). (b) The same as in (a), but the contribution to the wakefield from the second bunch is included.

RBT Algorithm For Transformer Ratio Enhancement

The previous analysis is generalized to a train of N drive bunches. Given the transformer ratio after the first ($n=0$) bunch (R_0) then the maximum transformer ratio that can be achieved after the n^{th} bunch (R_n) is,

$$R_n = (n+1)R_0 \qquad (n = 0,1,2,\ldots N\text{-}1) \qquad (1)$$

This maximum enhancement of the transformer ratio can only be achieved if the following conditions are satisfied. The separation between the bunches (see 'd' in Fig. 1b) is $1/2$ integer or,

$$d = (m + 1/2)\,\lambda_0 \qquad (m = 1,2,\ldots,N\text{-}1) \qquad (2)$$

where λ_0 is the fundamental wavelength of the structure. The charge ratio of the individual bunches within the train increases according to,

$$Q_n = Q_0\;[nR_0 + 1] \qquad (n=0,1,2,\ldots N\text{-}1) \qquad (3)$$

where Q_0 is the charge in the first drive bunch. In addition to the requirements of spacing (Eqn. 2) and relative charge ratio (Eqn. 3) for the bunch train, there are also two requirements on the single bunch for obtaining maximal transformer ratio enhancement. The first condition is in addition to the work of [3]. The self-wake generated by the single bunch must be symmetric with respect to the center of the bunch. In other words, for a gaussian distribution, centered at $z = 0$, the self-wake within the bunch must satisfy, $W_0^-(-z) = W_0^-(+z)$. If this 'symmetric, single wake' condition is not met, the self-wakefields of the trailing bunch will be phase shifted from the accelerating bucket of the leading bunch resulting in only a partial cancellation of the fields. This can be corrected by changing the spacing ('d' in Fig. 1) of the bunches within the train so that full cancellation is obtained, but since it is easier to generate a bunch train of equal spacing we choose to satisfy the above condition. Numerical simulations show that the 'symmetric, single wake' condition is met when the bunch length satisfies

$$\sigma/\lambda_0 = 0.2 \qquad (4)$$

For a given R_0, the transformer ratio is maximized if the conditions specified in Eqn. 2, Eqn. 3, and Eqn. 4 are satisfied. This means that if $R_0 = 1$, then the fastest R_n can increase is $R_0 = 1$, $R_1 = 2$, $R_2 = 3$, $R_3 = 4$, etc. However, if $R_0 = 2$, then R_n could increase as $R_0 = 2$, $R_1 = 4$, $R_2 = 6$, $R_3 = 8$, etc. Therefore, since our goal is to maximize R_n we desire $R_0 = 2$ and therefore, bunch length satisfies,

$$\sigma/\lambda_0 = 0.25 \tag{5}$$

as shown in the previous section. Although the last two conditions cannot be satisfied simultaneously, an intermediate value is sufficient for our experiments.

DIELECTRIC AND PLASMA EXPERIMENTS

In this section we outline plans for two experiments to be performed at the AWA. First we describe in some detail a DWFA experiment and finish by sketching a PWFA experiment.

Transformer Ratio Enhancement Using A RBT To Excite A DWFA

The available bunch length and finite group velocity considerations drove the choice of the structure for the DWFA experiment at the AWA facility. The upgraded AWA facility [6] will be able to produce a 40 nC beam with 1 mm of charge. For our experiment we use a conservative bunch length of $\sigma = 1.5$ mm. Based on the RBT algorithm we want $\sigma/\lambda_0 = 0.2$ and thus choose the dielectric structure of the previous section with $\lambda_0 = 7.89$ mm (the wavelength of our previous examples). If we locate the second bunch in the first acceleration bucket (i.e. m = 1 of the previous section) after the first bunch we have $d = (m+1/2)\ \lambda_0 = (1.5)^*\ 7.89\ mm = 11.84\ mm$. We plot this example in Fig. 5a to show the position of the second bunch relative to the first bunch - its wakefield is not taken into account in the figure. The second consideration, finite group velocity, means that high ε is best, which can be understood as follows. Since the group velocity of the *rf* packet $\neq 0$, one must make sure that the length of the tube must be long enough so that the wakefields of the four drive bunches overlap. If the dielectric constant is high ($\varepsilon = 38$) then the group velocity is low; $\beta_g \approx c/\varepsilon = 0.026c$, where c is the speed of light. By the time the 4^{th} drive bunch enters the tube, the *rf* packet from the first bunch has traveled a distance $\beta_g 3d$ where 3d is the separation between the first and last bunch. Thus L only need to be greater than $\beta_g 3d$ or about 2 cm.

If we had an electron source that could produce bunches separated by 11.84 mm we could do the experiment as it is described. However, the last constraint we must consider for our design is due to the AWA facility. The AWA *rf* frequency is based on 1.3 GHz and therefore we can only produce drive beams separated by $\lambda_{rf} = 23$ cm. Since the dielectric structure of the previous section has $\lambda_0 = 0.8\ cm$, then we must operate at m^{th} harmonic of 23/0.8 or $m = 28^{th}$ harmonic.

Using the above DWFA with $\lambda_0 = 0.8\ cm$, we construct a bunch train according to the algorithm given above. We choose $\sigma/\lambda_0 = 0.2$, $d = (28 + 1/2)\ 0.8\ cm = 23\ cm$, and $Q_n = Q_0 = 3$, $Q_1 = 9$, $Q_2 = 15$, and $Q_3 = 21$. The resultant wakefield excited by this RBT is shown in Fig. 6. A close examination of Fig. 6 shows that each bunch experiences the same decelerating wakefield $W_n^- = -0.8$ MeV/m/nC, while the peak accelerating field behind each bunch W^+_n increases as $W^+_0 = 1.63$, $W^+_1 = 3.26$, $W^+_2 = 4.90$, and $W^+_3 = 6.54$ all in units of MeV/m/nC. This results in a transformer ratio behind each bunch as, $R_0 = 2$, $R_1 = 4$, $R_2 = 6$, $R_3 = 8$ or an overall transformer ratio for this experiment of 8.

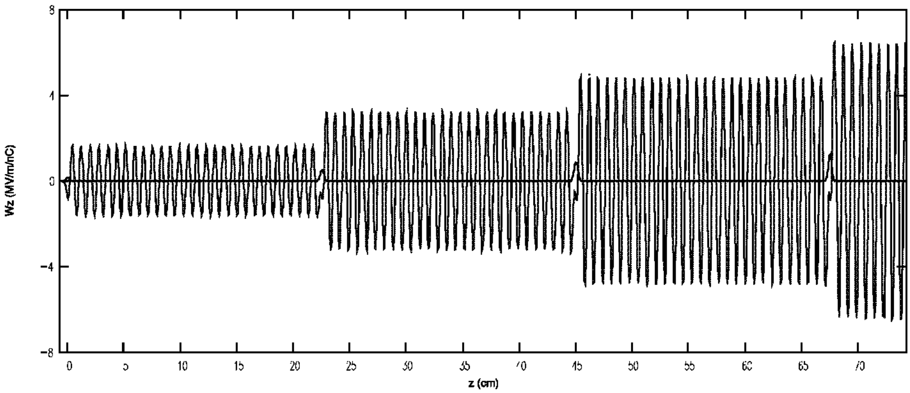


FIGURE 6. The resultant wakefield produced in a DWFA by a train of 4 electron bunches of bunch length 1.5 mm and charge magnitude $Q_0 = 3$, $Q_1 = 9$, $Q_2 = 15$, *and* $Q_3 = 21$. The Transformer Ratio $R = 8$ for this example.

Transformer Ratio Enhancement Using a RBT To Excite A PWFA

As a second example we briefly consider using a RBT to excite plasma wakefields. For a plasma density of $n_0 = 10^{14}$ /cm^3 we have a plasma wavelength of $\lambda_p = 0.334$ cm. For the PWFA experiment we choose a beam density of $n_b = 10^{14}$ /cm^3, bunch length $\sigma_z = 0.055$ cm, beam energy of 15 MeV, and normalized emittance of 40 mm mrad.

A bunch train of N = 5 bunches can be designed by using the above RBT algorithm. Given the fundamental wavelength of $\lambda_p = 0.334$ cm we choose $d = 1.5\lambda_p \sim 0.5$ cm as the bunch separation. (In this example we are using a slightly non-optimized case where $d = 1.45\lambda_p$ since we are using $\sigma_z/\lambda_p = 0.165$ and the condition of Eqn. (4) is not exactly satisfied.) Given $Q_0 = 5$ nC we have, $Q_1 = 15$, $Q_2 = 25$, $Q_3 = 35$, and $Q_4 = 45$. Lastly, we expect $R_0 \sim 2$ since $\sigma_z/\lambda_p = 0.165$, is near the optimal value of 0.2.

The peak plasma wakefield amplitude excited by a single bunch can be calculated by using the linear theory factor [7] in which the transverse ($\sigma_r^2 = \beta\varepsilon$) and longitudinal ($\sigma_z$) beam sizes, but not the gaussian dependency are included. Although we are not operating in the linear regime, this scaling law is consistent with detailed PIC simulations and should be a good indicator of wakefield amplitude. The amplitude is given by,

$$E_0 = 100\sqrt{n_0}\frac{n_b k_p \sigma_z}{n_0\left(1+\frac{1}{k_p^2\sigma_r^2}\right)} \tag{6}$$

where k_p is the plasma wave number and E_0 has units of V/m. If the beta function (β) is 10 cm we have $E_0 = 3.398*10^8$ V/m. The wakefield produced by a gaussian bunch of the above parameters is calculated (to first order) by convoluting the Green function solution of the plasma over a gaussian bunch distribution and scaling it by the linear theory factor, E_0. Finally, the wakefield excited by the entire bunch train is calculated (see Fig. 6) by invoking linear superposition.

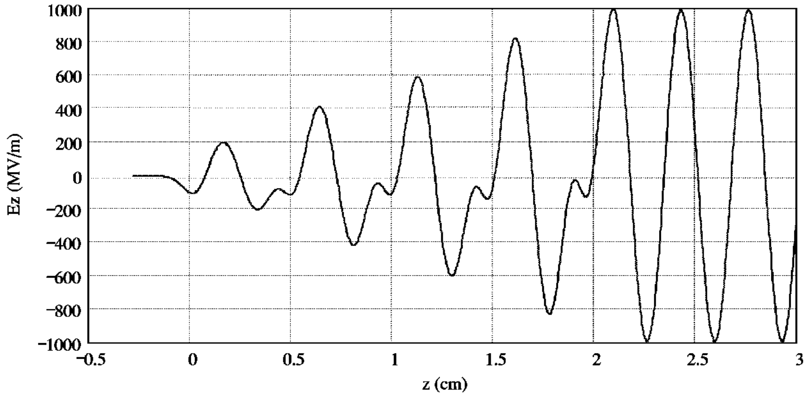


FIGURE 7. The resultant wakefield produced in a PWFA by a train of 5 electron bunches of bunch length 0.55 mm and charge magnitude $Q_0 = 5$, $Q_1 = 15$, $Q_2 = 25$, $Q_3 = 35$, $Q_3 = 45$. The Transformer Ratio R = 10 and the acceleration gradient is 1GV/m for this example.

The maximum accelerating fields after the bunches ($W^+{}_n$) are seen to ramp as, as $W^+{}_0$ = 200, $W^+{}_1$ = 400, $W^+{}_2$ = 600, $W^+{}_3$ = 800, and $W^+{}_4$ = 1000, all in units of MeV/m/nC while the decelerating fields are all equal to W^-_n ~ -100 MeV/m/nC. This results in a transformer ratio behind each bunch as, $R_0 = 2$, $R_1 = 4$, $R_2 = 6$, $R_3 = 8$, $R_4 = 10$ or an overall transformer ratio for this experiment of 10.

Tail Of The Distribution

If one examines Fig. 6 and Fig. 7 closely he will notice that the tails of the drive bunches spills over into the adjacent decelerating bucket. This means that the minimum decelerating field within the drive bunch train is larger than previously stated and the transformer ratio is therefore lower. To this there are two responses. First, the amount of charge contained in adjacent bucket is extremely small. For the example of the PWFA with σ_z/λ_p = 0.165 the total amount of charge in the adjacent decelerating bucket is < 1%. Second, just to show that this is a real effect, one could design an experiment using a multimoded DWFA [4] that has decelerating buckets spread very far apart so that no charge ends up in the adjacent bucket.

EXPERIMENTAL SETUP

In this section we describe how the RBT experiment can be done. We first describe how the bunch train is generated and the associated difficulties with transporting the RBT and finish with a discussion of how we will measure the transformer ratio.

Generation And Transport Of The RBT

A RBT of 4 electron bunches is made by optically splitting a single laser pulse into 4 separate pulses (in much the way as was done for the flat bunch train (FBT) experiments [4]) and sending these pulses into the AWA *rf* drive photoinjector [6]. The optical splitter for the RBT [8] differs from the FBT experiment in that splitters used in this case are not 50/50 ones but are chosen to produce the desired charge ratio. The distance between bunches is adjusted optically by moving mirrors on translation stages in the delay line. Initially, the distance between bunches is crudely measured with a streak camera, using the 10 ns sweep rate, thus giving us a timing resolution of ~10 ps between bunches. Final bunch spacing must be done during the experiment by making the deceleration of trailing bunches equal to the deceleration of the lead bunches after they emerge from the dielectric structure. Although it is easy to generate the laser pulse train with the correct intensity using the optical splitter, it may be difficult to transport the electron bunches down the accelerator. This is because the electron charge of the first bunch is so much less than that of the last bunch, that it will not be possible to run the accelerator system at an optimized machine tune for either bunch. (For example, Q_0 = 3 nC & Q_3 = 21 nC in the DWFA experiment.)

Measurement Of R

To measure the transformer ratio R, we must infer the deceleration gradient, W^-, experienced by the four drive beams by measuring their energy loss after emerging from the dielectric structure of Fig. 2. Since all drive beams will experience the same decelerating field, we will only be able to measure the combination of the four beams with our spectrometer (Fig. 8).

The energy will be measured with the spectrometer shown in Fig. 8. The energy measurement system has a resolution of 0.2% with the tungsten slit set to 300 µm. To complete the measurement of the transformer ratio, one must also know W^+ behind each bunch – i.e. one must map out the wakefield left behind the drive bunch train with a witness beam. For a length of tube $L = ½\ m$, we expect the drive bunches to only lose 0.4 MeV. Thus the drive beam will exit the structure with 15.2 MeV – 0.4 MeV = 14.8 MeV. The witness beam will enter the structure with 4 MeV and receive a maximum acceleration of 3 MeV thus exiting with energy of 7 MeV.

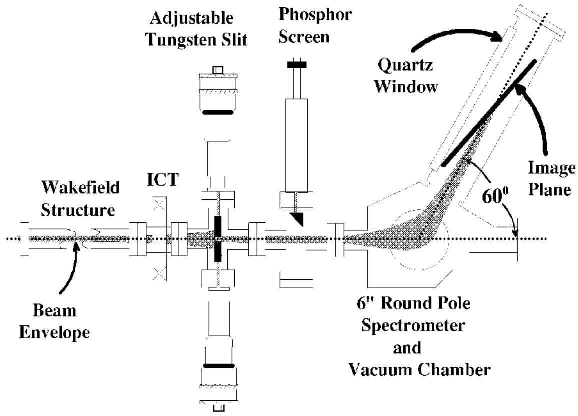


FIGURE 8. Energy Measurement System. The decelerated drive bunch train passes through a tungsten slit of adjustable width, which is imaged through a 60^0 dipole (diameter = 6") onto a phosphor screen located at the image plane. The phosphor screen is viewed with an intensified camera through the quartz window.

SUMMARY

We have described how to use the RBT method to achieve a transformer ratio (*R*) greater than 2 in any collinear wakefield accelerator – i.e. in either plasma or structure based wakefield accelerators. We presented an algorithm for designing a RBT experiment and have outlined two experiments for obtaining $R >> 2$ in both a DWFA and a PWFA. We believe this method is feasible from an engineering standpoint using existing technology. An experiment to be preformed at the AWA facility to measure a R >> 2 in a collinear DWFA is planned for the near future. Achieving $R >> 2$ could have important implications for the future development of any collinear wakefield accelerator.

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