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Short-pulse dielectric two-beam acceleration

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Abstract. We are exploring a new parameter space of the two-beam acceleration (TBA) scheme based on an ultra-short (∼20 ns) rf pulse in a dielectric TBA. All two-beam accelerators (TBAs) use an electron drive beam to generate high-power rf in a decelerator and extract this power to drive an accelerating structure to high gradient. Typically, the rf pulse is on the order of hundreds of ns or greater in order to maintain good rf-to-beam efficiency. However, recent scaling arguments show that the rf breakdown threshold improves with decreasing rf pulse length, so it desirable to find a way to run at short-pulse length with good efficiency. In this paper, we discuss how we chose the design parameters of a short-pulse TBA for a TeV linear collider module. We then present plans for an experimental program to demonstrate TBA at Argonne wakefield accelerator (AWA) facility including high-power rf generation, high-gradient acceleration, and staging.

1. Introduction

Ongoing efforts toward a TeV scale electron-positron linear collider from the International Linear Collider (ILC) and Compact Linear Collider (CLIC) teams have been well established [1, 2]. Both proposed machines work at frequencies within microwave range. The ILC, which uses superconducting cavities, is designed to operate at an rf pulse length of 1.5 ns and loaded gradient of 35 MV/m. CLIC, which is based on the room temperature two-beam accelerator (TBA) scheme, operates at an rf pulse length of 240 ns and loaded gradient of ∼100 MV/m. On the other hand, alternative designs for high-energy machines (HEP) continue since a practical machine has many challenges besides physics, including cost. For example, futuristic HEP using plasma or laser based wakefield acceleration schemes are under investigation, where accelerating gradients in the GV/m level have been demonstrated in various experiments [3–5]. In this paper, we present potential path to an HEP machine based on the short-pulse concept.

Although the physics behind rf breakdown is not fully understood, observations from numerous experiments reveal that the rf breakdown threshold in accelerating structures increases when the rf pulse length decreases [6, 7]. In current, room temperature, and high-gradient accelerator designs, ∼150 MV/m gradient with a pulse length in the range of 200–400 ns is usually the limit of normal operations [7]. In addition, rf power sources on the order of ∼GW are required to power accelerating structures to tens of hundreds MV/m level, which implies a new type of power generation other than klystron is needed. Due to their simplicity of manufacture and the possibility of a high breakdown threshold, a short-pulse (∼20 ns) TBA based on dielectric traveling wave (TW) structures is a good candidate to meet the requirements for future HEP machines. The key of the program at the Argonne wakefield accelerator (AWA) is to demonstrate that this scheme can achieve high efficiency, low cost, and compact size while operating at high gradient (∼250 MV/m).

One concern raised about the short-pulse TBA concept is that its efficiency, which depends on several factors, will be too low. In particular, the concern for the short-pulse accelerator is that the rf overhead, or the fraction of the rf pulse that cannot be used for beam acceleration, is too high. The total length of the rf pulse ($T_{\rm rf}$ in Fig. 1) consists of a segment that can be used to accelerate the beam ($T_{\rm beam}$) and an rf transient segment that cannot be used for acceleration. This rf transient time is composed of the rise/fall time ($T_{\rm rise}$) due to the bandwidth of the coupler plus the filling time of the TW structure ($T_f = L/v_{\rm g}$). One can show that the rf overhead is equal to ($T_{\rm rise} + T_f - L/c$) so that $T_{\rm beam} = T_{rf} - (T_{\rm rise} + T_f - L/c)$ and that the fraction of the rf pulse available for acceleration is $T_{\rm beam}/T_{\rm rf}$. Given this, the rf-to-beam efficiency ($\eta_{\rm rf\text{-}beam}$) can be expressed as the product of the efficiency due to beam loading ($I_{\rm beam}E_{\rm load}L_{\rm s}/P_{\rm rf}$) times the fraction of the rf pulse available for acceleration,

$$\eta_{rf\text{-}\rm beam} = \left(\frac{I_{\rm beam}E_{\rm load}L_{\rm s}}{P_{\rm rf}}\right) \times \frac{T_{\rm beam}}{T_{\rm rf}}, \qquad (1)$$

where $I_{\rm beam}$ is the average beam current inside the rf pulse; $E_{\rm load}$ is the average loaded gradient; $L_{\rm s}$ is the effective structure length; $P_{\rm rf}$ is the input rf power; $T_{\rm beam}$ is the period of time that beam appears. We can maximize rf-to-beam efficiency by first optimizing beam loading (first term in [1]) that can easily be done choosing an accelerator structure that operates

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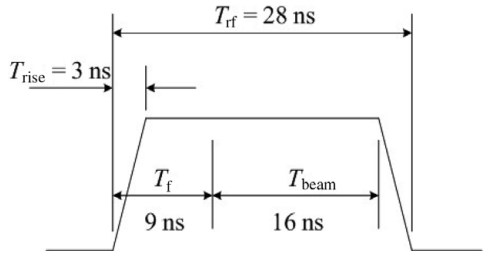


Figure 1. The 26 GHz rf pulse envelope for the short-pulse TBA concept.

at a relatively high frequency (f) since the beam current $I_{beam} = Q \times f$. Note that the beam loading cannot be maximized since it is a trade off against maintaining a reasonable loaded gradient. Next, we have developed several methods to maximize the fraction of the rf pulse available for acceleration (second term in [1]). (1) Use the TBA scheme in the decelerator to avoid the slow rise time of klystrons (i.e. T_{rise} is short). (2) Use broadband accelerator structures to reduce the rise and falling time of rf pulse (i.e. keep T_{rise} short). (3) Use accelerator structures with large group velocity and relatively short length to reduce the filling time (i.e. keep T_f short). Figure 1 shows the rf pulse structure we proposed in a 26 GHz short-pulse TBA collider [8], which has a 9 ns of filling time (~30 cm long accelerating structure and group velocity of ~11% of speed of light) and 3 ns of rf rise/fall time, resulting in the 16 ns beam time over total 28 ns rf pulse length ($T_{beam}/T_{rf} = 57.1\%$).

In the following sections, we first briefly introduce the design of a short-pulse dielectric TBA module that was developed for the 3-TeV for the Argonne flexible linear collider [9] (the concept for a short-pulse linear collider being developed at Argonne). In Sec. 3, we present the design and experimental testing plan for both the high-gradient accelerator and wakefield power extractor (WPE) (a decelerator + output coupler) to demonstrate the short-pulse, rf acceleration concept. In Secs. 4 and 5, we discuss initial plans for a demonstration of staging and its experimental design at AWA facility; final remarks are presented in Sec. 6. We emphasize that the examination of many important parameters are not covered in this paper due to space constraints, although it is clear that more effort is needed to realize the short-pulse concept. We hope that this paper will shed some light on some of the real design issues for a possible future HEP collider.

2. A short-pulse dielectric TBA module

A 3-TeV linear collider scheme based on the short-pulse TBA concept was proposed recently at AWA facility [9]. It consists of 10, 150 GeV modules, operating at $f_{rf} =$ 26 GHz, that generate the 1.5 TeV electron beam and another 10 modules to generate the 1.5 TeV positron beam. Figure 2 shows the main content of one 150 GeV module, which is made up of 50×3 GeV submodules sharing one drive beam source. This looks like the CLIC

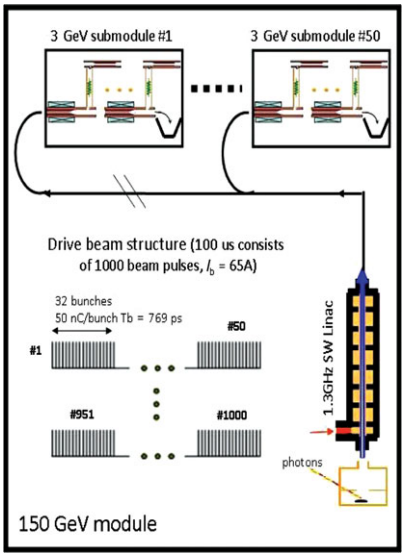


Figure 2. (Colour online) Schematic layout of a short-pulse, 150 GeV, dielectric-based, TBA module at 26 GHz.

scheme except for a few critical differences. Firstly, in one module, 1000 (=50×20) drive microbunches, spaced by $f_{rf}/2$ for a train duration ~24 ns, pass through 50 submodules with a local beam pulse repetition rate of 20. This represents 20×5 μs long macrobunch train as well. Each module provides 3 GeV gain, which adds up to 150 GeV after 50 submodules. Overall, these 1000 microbunches, which is organized by 20, 5 μs long macrobunches, form a 100 μs giant beam pulse. In addition, the machine repetition rate is 5 Hz. Secondly, to match the local beam pulse repetition rate of 20, the main beam consists 20 short bunches in the same 100 μs period of time. The main beam current inside a ~24 ns pulse is chosen to be $I_{beam} = 6.5$ A, which corresponds to $Q = 0.5$ nC per bunch spaced at $f_{rf}/2$. The advantage of operating at high-rf frequency is that the current can be relatively high while keeping the charge per bunch is low which makes it easier to achieve high beam quality.

Another obvious difference from the CLIC scheme is that the drive beam in this short-pulse scheme is generated by a 1.3 GHz rf photoinjector in one 150 GeV module with a high QE cathode, which can provide 50 nC/bunch with a bunch separation of 769 ps (32 sequential bunches form a ~24 ns micro drive pulse) [10]. This high charge beam can produce an rf pulse with 22 ns flattop at ~1.3 GW using our 26 GHz WPE [11]. Finally, to achieve a high rf-to-beam efficiency in the main linacs under the short rf pulse condition, we choose a high frequency (26 GHz), high group velocity (~11% c), and dielectric based structure (broadband rf coupling), which in turns provide ~270 MV/m of gradient (with assumption of no breakdowns at this level in a 20 ns pulse duration), ~9 ns filling time, and ~3 ns rise time. Plugging these numbers to (1), 26% of the rf to main beam efficiency is obtained, and the total efficiency was shown to be 7.2% [9].

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Every 3 GeV submodule contains $N = 38$, $L = 0.3$ m long TBA pairs (WPE and main accelerator). The total length of one submodule is 15 m, which matches the time periodicity of micro drive bunches (100 ns). The drive beam pulses are evenly distributed along a common transportation line in parallel but traveling with an opposite direction to the main beam so that the distance between drive bunches has to be twice the length of one accelerating structure to ensure the arrival time at the entrance of WPE matching with the main beam. The WPE is one to one mapped to the accelerating structure to satisfy the GW level rf power requirement of the main accelerating structure (Since the high group velocity of main linac design, it requires more rf power [>1 GW] to build up the unloaded gradient ~300 MV/m). In every 3 GeV module, the drive beam is 0.86 GeV at entrance of the first WPE. It loses 20.5 MeV per every WPE and provides 1.33 GW rf output. The drive beam drops to 80 MeV after 38 extractors and is dumped at the end of the 3 GeV module.

3. A short-pulse dielectric TBA submodule

As shown in the Fig. 2, the single TBA stage includes three basic elements. (i) a WPE that consists of a decelerator for extracting rf power from the drive beam and an output coupler to extract the rf power from the decelerator. (ii) an rf transfer waveguide to transport the rf power from the power extractor to the accelerating structure. (iii) an accelerating structure where the rf power is delivered to main beam.

In our current short-pulse TBA design, we chose a dielectric-based WPE (DWPE) for several reasons. The dielectric based accelerator/decelerator (in this paper, we refer to circular, constant impedance, dielectric loaded structured unless specially mentioned) has no or very low enhancement of the electric field on inner dielectric surface over compared to that on axis (no enhancement for the longitudinal component and normal component Er $= \pi a/\lambda$ under the synchronized condition, where a is beam aperture and λ is the wavelength) [12]. This is particularly important because of >150 MV/m of gradient for the nominal rf power output, 1.33 GW. Some other advantages of using dielectric based structure include the potentially higher breakdown threshold, simple geometry (easy fabrication and low cost), and convenient parasitic mode damping [13]. The dielectric based decelerator is a constant impedance structure because of the uniformity of the dielectric constant and beam channel along the structure. The generated rf power by an ultra-relativistic bunch train in such a decelerator is given by [14]:

$$P = \frac{1}{4}\frac{\omega}{v_g}\frac{r}{Q}L^2I^2F^2\left(\frac{1-e^{-\alpha L}}{\alpha L}\right)^2 \qquad (2)$$

where I is the beam current (the charge per bunch over the bunch spacing), L is the active length of the decelerator, ω is the angular frequency of the rf mode, v_g is the group velocity, (r/Q) is the shunt impedance per unit length over quality factor, α is the attenuation per unit length, and F is the single bunch form factor. The major design parameters of the 26 GHz DWPE are summarized in Table 1. 1.33 GW steady power is generated with 65 A drive beam. Taking account 5% loss from coupler and waveguide transportation system, 1.26 GW 26 GHz short rf pulse is expected to deliver to the main accelerator.

Table 1. Parameters of 26 GHz dielectric based wakefield power extractor (DWPE).

Geometric and accelerating parameters	Value
ID/OD of dielectric tube	7 mm/9.068 mm
Dielectric constant	6.64
Length of dielectric tubes	300 mm
Vg	0.254 c
R/Q	9788 Ω/m
Rf pulse rise time	2.9 ns
BW_{-3dB} of the requested coupler	120 MHz
Steady power (50 nC/bunch, $\sigma z = 1$ mm)	1.33 GW
rf pulse duration (32 bunches)	22 ns (flat top)
Peak gradient	167 MV/m
Energy loss of the beam in the steady state	20.5 MeV

Table 2. Parameters of the 26 GHz dielectric based accelerator.

Geometric and accelerating parameters	value
ID/OD of dielectric tube	3 mm/5.025 mm
Dielectric constant	9.7
Length of dielectric tubes	300 mm
V_g	11.13% c
T_{fill}	9 ns
R/Q	21.98 kΩ/m
$Q(\tan\delta = 10^{-4})$	2295
Shunt impedance	50.44 MΩ/m
BW_{-3dB} of the requested coupler	120 MHz
E_{acc} for 1.26 GW input	316 MV/m
E_{load} for 1.26 GW input	267 MV/m

For similar reasons, we prefer to use dielectric-loaded accelerating (DLA) structures in the proposed short-pulse TBA module. Major parameters of the 26 GHz DLA structure are summarized in Table 2.

Recently, we developed a prototype 26 GHz DWPE (version with no transverse mode damping) and performed an initial high-power test on the AWA 15 MeV test beamline. Despite some non-ideal experimental conditions, like a non-ideal bunch length (2 mm instead of 1 mm) and low beam current, a very good initial rf pulse was measured, 20 MW at the rate of 26 GHz [11]. Currently, a 26 GHz DLA structure with parameters shown in Table 2 is under development. The first short-pulse acceleration experiment will be performed on the new 75 MeV drive beamline (under construction) at AWA facility [10, 16]. It can produce a variety of bunch trains of up to 32 electron bunches and up to 100 nC per bunch, although not simultaneously. Figure 3 shows an example of a bunch train composed of 16

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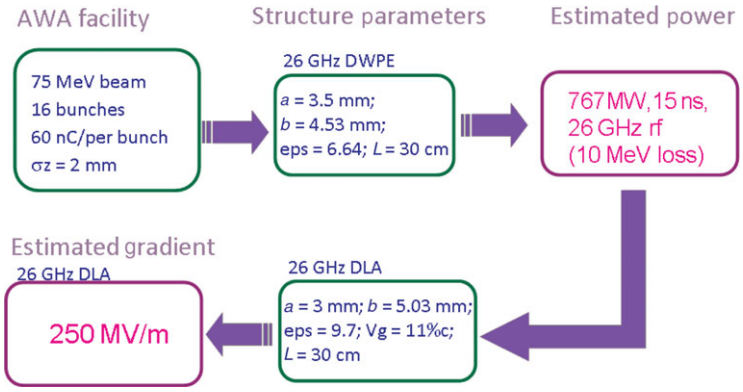


Figure 3. (Colour online) Projected rf power and achievable gradient for the high-power rf test of the 26 GHz broadband DLA structure at the AWA facility.

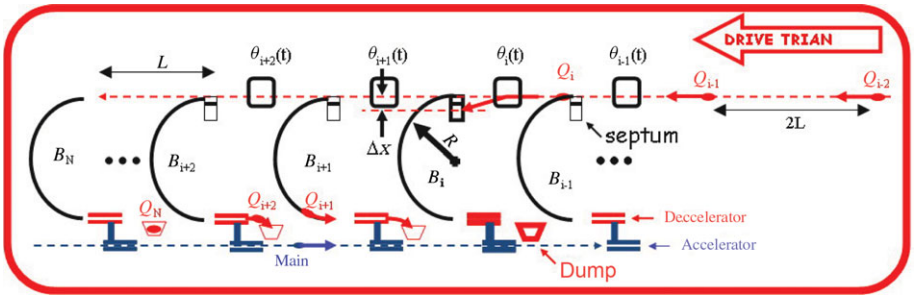


Figure 4. (Colour online) Schematic diagram of a simplified staging beamline. It notes that the decelerator and accelerator pair shown here represents a sub-module shown in Fig. 2.

bunches spaced by 0.77 ns with up to 60 nC per bunch, corresponding to six GW's of beam power. Using this drive beam, 767 MW rf power can be generated by the existing 26 GHz DWPE that in turn will produce a 250 MV/m gradient inside the 26 GHz broadband dielectric accelerator structure. Considering rf power loss in the rf transport and losses from couplers and dielectric structures, >500 MW rf input and >200 MV/m gradient are expected.

4. Staging

One of the critical issues for the short-pulse TBA concept is staging [15] – the temporal synchronization of the sub-modules required to accelerate the charged particles to high total energy. Each accelerating submodule delivers an increment of energy to a passing charged particle bunch. When many such submodules are staged in a row, the charge particle bunch is accelerated to high energy. Figure 4 shows a simplified schematic of a staging beamline for the dielectric TBA. The purpose of the staging beamline is to deliver the drive bunches at the appropriate time to the decelerator stages for acceleration of the main beam in the accelerator. We want to deliver a drive beam, Q_i, ($i = 1 \ldots N$, where N is the number of bunches in the drive train) through an isochronous turnaround beamline, B_i, and into the decelerating structure, $deceleator_i$ Thus, the staging beamline has two main components:

- fast bending element, $\theta_i(t)$, to extract the last drive bunch remaining in the train (Q_i) while allowing the leading bunches to pass through;
- isochronous turnaround beamline, B_i, to deliver the drive beam to the decelerator.

The isochronous beamline is not discussed in this paper but is believed to be reasonably straightforward. In the remainder of this paper, we discuss the general requirements of the fast bending element and consider a design for the AWA staging beamline based on a deflecting cavity.

4.1. The general requirments of the bending element

The requirements for the fast bending element are its time response (rise time, flattop, and fall time) and amplitude ($\theta = \Delta\theta$); they are arrived at as follows. A train of drive bunches, separated by $2L$, where L is the separation between stages (Fig. 4), arrives from the drive linac to the staging beamline. The bending element must remain off ($\theta = 0$) until the leading bunches ($Q_N, Q_{N-1}, \ldots Q_{i+1}$) have passed through and then it must turn fully on ($\theta = \Delta\theta$) before the bunch to be extracted (Q_i) arrives. This means the bending element risetime is $t_{rise} = 2L/c$. We note that the fall time is not demanding since we are extracting the last drive bunch in the train. The required amplitude of the bend ($\Delta\theta$) comes from the fact that the drive beam of momentum p_0 must be deflected into the septum magnet. If the bending element is placed after the turnaround

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arc of radius, R, then the distance between the bending element and the septum magnet is approximately $L - R$. Therefore, the offset at the septum is,

$$\Delta x = \Delta\theta(L - R) \tag{3}$$

If the deflecting element imparts a transverse momentum $\Delta p_\perp$ to a beam with momentum p_0, then the bend angle is,

$$\Delta\theta = \Delta p_\perp / p_0 \tag{4}$$

5. Staging at the AWA facility

Demonstration of staging in a dielectric TBA is being planned after completion of the upgrade to the AWA facility [10, 16]. Initial estimates show that two stages separated by $L = 8$ m will fit into the bunker with a turnaround beamline of *radius* ~4 m. The 100 nC drive beam has a large transverse size, approximately $6\sigma = 25$ mm, and therefore needs to be kicked off axis by a correspondingly large amount. For an offset $\Delta x = 50$ mm and separation $L - R = 4$ m, then the required bend (4) is $\Delta\theta = 12.5$ mrad. In addition, the risetime of the bending element (as outlined above) is $t_{\text{rise}} = 2L/c$. For a drive bunch separation of $2L = 16$ m the corresponding risetime is, trise 50 ns.

The above considerations show that it will be difficult to demonstrate staging in the AWA facility due to the limited space in the bunker. In summary, the required bend angle and rise time are,

$$\begin{aligned} \Delta\theta &= 12.5\,\text{mrad} \\ t_{\text{rise}} &= 50\,\text{ns} \end{aligned} \tag{5}$$

which are not difficult to achieve separately, but the combination of the large kick and the fast risetime is a challenge. However, since we are in the early stages of developing the plan for staging, we are now considering a number of possibilities to serve as a starting point.

5.1. A stripline kicker as the bending element

We consider a stripline kicker [17] consisting of a pair of parallel plate striplines of length S and gap separation d. A transverse voltage $V_\perp$ applied across the plates produces an electric field of $E = V_\perp/d$. Solving the equation $\mathrm{d}p/\mathrm{d}t = eE$ and substituting $\mathrm{d}t = \mathrm{d}s/c$, then the transverse momentum imparted to the beam is,

$$\Delta p_\perp = \frac{1}{c}\frac{eV_\perp S}{d} \tag{6}$$

and therefore, the bend angle is,

$$\Delta\theta = \frac{eV_\perp}{T_0}\frac{S}{d} \tag{7}$$

where T_0 is the kinetic energy of the beam and the approximation $p_0 c \approx T_0$ was used.

In order to achieve the required amplitude of the bend ($\Delta\theta = 12.5$ *mrad*) we substitute into (7) with $S = 30$ cm, $d = 50$ mm, and $T_0 = 75$ MeV to find the required transverse voltage, $V_\perp = 156$ kV. This is a large voltage and the options for reducing it are limited to increasing S or decreasing d. The former is problematic because the separation between the kicker and the septum is only 4 m while the later is difficult since the 100 nC beam has a large transverse envelope. We will consider using focusing elements to reduce the transverse size of the drive beam to reduce the required kick. The risetime of the kicker, as outlined above is, $t_{\text{rise}} = 2L/c = 50$ ns. Taken together, this would require the development of a very challenging power supply to provide a high voltage (156 kV) and fast risetime (50 ns) output.

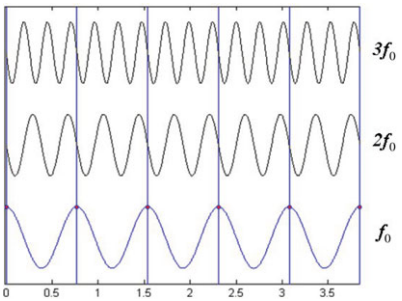


Figure 5. (Colour online) Harmonic Cavity does not work.

5.2. A long pulsed deflecting cavity as the bending element

We next consider an rf deflecting cavity ("deflector") [18] for the bending element. By long pulse, we mean that the rf deflector is at full rf power for the duration of the entire pulse train. The deflector operates in a TM_{110}-like mode and according to the Panofsky–Wenzel theorem [19] the transverse momentum imparted to the bunch is given by,

$$\Delta p_\perp = \left(\frac{je}{\omega}\right)\int_0^L \nabla_\perp E_z dz. \tag{8}$$

An evaluation of the integral in (8) requires the numerical simulations of the cavity fields. To estimate the requirements of the deflector, we scale the values from an existing AWA deflector [20]. The transverse deflection voltage ($eV_\perp \approx \Delta p_\perp$) corresponds to maximum deflection voltage provided by the cavity when the beam pass through the cavity "on-crest". (This is as opposed to applications where the beam passes through the cavity at "zero-crossing" to be streaked by the cavity.) The AWA deflector normalization is $V_\perp = 3.4$ MV at $P = 4.2$ MW. Since the voltage scales with the square root of the power, then the power required for $V_\perp = 156$ kV is only $P = 8.8$ kW. This is a very modest amount of rf power.

Achieving a large amplitude kick from an rf deflector is trivial as the previous analysis shows. The challenge in using an rf deflector is not the magnitude of the kick but the timing of the kick. The difficulty is that the deflector must allow an arbitrary number of beams to pass through at the zero-crossing (so that the bunches are not deflected) and then kick the last one. This prevents the use of a simple subharmonic or harmonic cavity based scheme as we now show. Consider the use of harmonic cavities, nf_0. The problem is (Fig. 5) when all drive bunches have the same phase (on crest in Fig. 5) of f_0, they will also have the same phase ϕ_i of f_i. And

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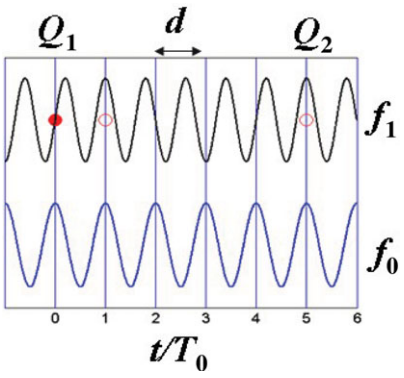


Figure 6. (Colour online) Timing relationship of the fundamental cavity frequency (f_0) and the non-harmonic cavity frequency (f_1) for the two-bunch case.

while one can shift the value of ϕ_i, all drive bunches will still receive the same kick.

A solution to the above problem of using rf deflectors as the bending elements in the staging beamline has been found based on the use of non-harmonic rf deflecting cavities for N bunch trains of $n = 1$ bunch each. We first analyze the simplest case (two stages, $N = 2$ trains) and then show the general results. Given the fundamental accelerating frequency of the drive bunch train, f_0, we choose an rf deflecting cavity operating at $f_1 = [1 + (1/4) \times f_0]$ (Fig. 6). If the first beam Q_1 (filled circle) is placed at normalized time, $t/T_0 = 0$ (where $T_0 = 1/f_0$) and the trailing bunch Q_2 (empty circle) is placed 1(5) fundamental rf period later ($t/T_0 = 1.5$), then Q_1 will pass through the cavity undeflected while Q_2 will get kicked. In general, the separation between the bunches must satisfy $d = (2m + 1)\lambda_0$ where $m = 0, 1, \ldots \infty$. This separation in turn imposes a restriction on the distance between stages so that $2 \times L = (2m + 1)\lambda_0$.

Briefly, we state the results for the general case of N bunch trains of $n = 1$ bunches. The frequency of the ith deflecting cavities (C_i) is,

$$f_i = f_0 \times (1 + 1/2^{1+i}) \quad \{i = 1, 2, \ldots, N\} \tag{9}$$

From (9), we see that the frequencies could be called fractional harmonics of the fundamental. In the simplest case, the minimum separation ($d_{i,i+1}$) between bunches i and $i + 1$ and the separation between the stages ($L_{i,i+1}$) is,

$$d_{i,i+1} = \lambda_0 \times 2^{N-i} \quad \{i = 1, 2, \ldots, N\} \tag{10}$$

$$L_{i,i-1} = 2d_{i,i-1}. \tag{11}$$

This separation is the minimum but can be increased as long as it is a multiple of the minimum distance.

We have not worked out the general case for kicking long ($n > 1$) bunch trains of arbitrary numbers of bunches ($N > 1$). Figure 7 shows the timing diagram for the case of $N = 2$ bunch trains of $n = 4$ bunches using an rf deflecting cavity of $1.25 \times f_0$. This solution allows the first train to pass through the deflector and successfully kicks "train 2." However, in order for this scheme to work, the minimum spacing between the N bunches was 5 wavelengths ($5 \times c/f_0$, where $f_0 = 1.3$ GHz). For the scheme outlined in the previous sections to work best, the spacing needs to be 1 wavelength; therefore, in order to use an rf deflector for long bunches the TBA module above would need to be reoptimized to work with longer bunch spacing. In the future, we will investigate whether it is possible to find a solution that operates at a higher harmonic of f_0 but still modified by the same fractional part shown in parenthesis to reduce the bunch spacing.

5.3. *A short-pulsed deflecting cavity as the bending element*

The requirements of the bending element (5) make the straightforward use of a stripline kicker or a long-pulsed rf deflector challenging. We have seen that the deflection of the kicker is too weak while the long-pulse deflector places too much of a restriction on the train spacing. Therefore, we will also consider an rf deflector can be brought to full rf power in under 50 ns or have its rf phase adjusted in under 50 ns.

It would be difficult to bring the rf cavity outlined in the previous section to full power within 50 ns because it takes a long time to fill a high-Q cavity ($2Q/\omega$) and the lack of availability of short risetime rf power supplies. To address the first problem, we are considering a traveling-wave waveguide to reduce the fill time (L/v_g). On the second point, we run into the same difficulty, as with the DC power supply for the stripline kicker, there is a lack of high-power, short risetime power supplies. However, as shown in the previous section, the rf power requirement for the 1.3 GHz rf deflector was modest, only $P = 8.8$ kW. This power requirement can be further reduced by using an rf deflector at higher frequency [21]. Initial estimates show that when using an x-band rf deflector the rf power required is reduced by a factor of 100. Given this, the requirement for an rf

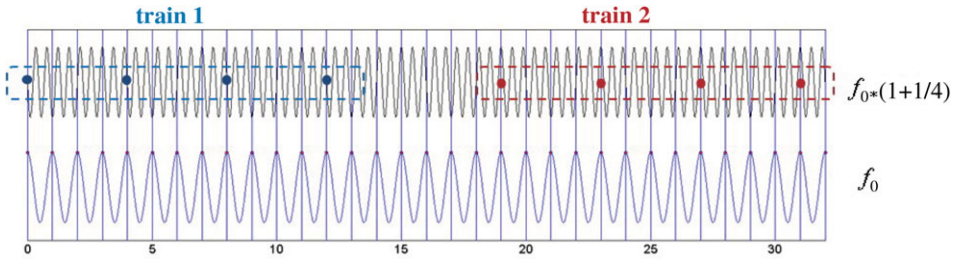


Figure 7. (Colour online) The rf deflecting cavity example with $N = 2$ bunch trains of $n = 4$ bunches.

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power supply is 100 W and 50 ns. Our initial search of commercial rf power supplies show that 100 W, x-band, power supplies can shift the phase within 10 ns. Therefore, we believe that this last option may be the most viable.

6. Remarks

The motivation for moving to the short-pulse regime is to achieve high-gradient acceleration. The introduced local repetition rate of the drive beam and the overall modular design make the scheme more flexible and expandable to meet different needs. We would like to emphasize that the proposed scheme does not strictly depend on whether the dielectric structure concept works or not, but any broad band accelerating structure that can sustain high gradients under short pulses can also be employed.

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