A FAST KICKER FOR A STAGED DIELECTRIC TWO-BEAM WAKEFIELD ACCELERATOR*

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Abstract

An experimental program to demonstrate staging in a dielectric two-beam wakefield accelerator (dielectric TBA) is being planned at the Argonne Wakefield Accelerator (AWA) facility. We are planning an experiment that both fits in the AWA tunnel and mimics conditions similar to the recently presented conceptual design of a linear collider based on the dielectric TBA [1]. This conceptual design is based on a new parameter space of the TBA scheme utilizing an ultra-short (~20ns) rf pulse in a dielectric TBA. The decelerating structures are driven by a series of drive microbunch trains that are 20 ns in duration and separated by 100 ns. This means that the fast kicker must have an extremely quick risetime as well as become stable within about 50 ns. In this paper, we consider designs for a fast kicker based on RF deflecting cavities and stripline kickers.

DIELECTRIC TWO-BEAM WAKEFIELD ACCELERATION

Dielectric two-beam wakefield acceleration (dielectric TBA) is one of the leading candidates for a high gradient accelerating structure [2-4] and is being pursued at the Argonne Wakefield Accelerator (AWA) [4] facility. In two-beam wakefield acceleration (TBA) [1, 4], a high charge drive beam is passed through a structure to generate high power RF which is then delivered into a second structure to accelerate a low-charge witness beam. Dielectrics structures are potentially an attractive choice due to the simple geometry (a dielectric cylinder with a vacuum hole down the center and surrounded by a metallic jacket), the easy damping of higher order modes, etc. A fundamental requirement of dielectric TBA that has yet to be demonstrated is the staging of sequential accelerating modules.

An experimental program to demonstrate staging [5] in a dielectric two-beam wakefield accelerator (dielectric TBA) is being planned [6] at the Argonne Wakefield Accelerator (AWA) facility. In this paper, we begin by discussing the requirements of the fast kicker and then review several options.

FAST KICKER REQUIRMENTS

A generic TBA staging beamline (Fig. 1) is described in detail in Ref. 6 but only summarized here. A train of drive bunches, separated by *2L*, where *L* is the separation between stages, arrives from the drive linac to the staging beamline. The bending element must remain off (θ=0) until the leading bunches (Q_N, Q_{N-1}, … Q_{i+1}) have passed

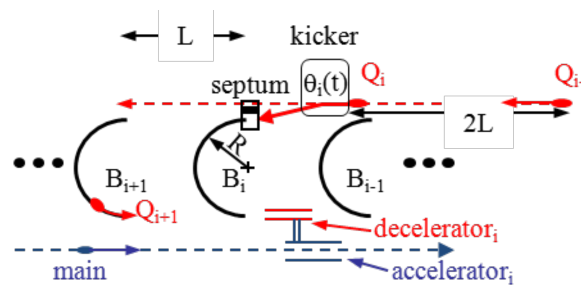

Figure 1: Generic TBA staging beamline.

through and then it must turn fully on ($\theta=\Delta\theta$) before the bunch to be extracted (Q_i) arrives. This means the kicker risetime is,

$$t_{rise} = 2L/c \tag{1}$$

We note that the falltime 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 turn-around arc of radius, R, then the distance between the bending element and the septum magnet is approximately L-R. Therefore, to achieve an offset, Δx, at the septum the required bend angle is,

$$\Delta\theta = \Delta x/(L - R) \tag{2}$$

In summary, the requirements for the time dependent kick, $\theta_i(t)$, of the fast kicker are set by its risetime (Eq. 1) and amplitude (Eq. 2).

THREE STAGING BEAMLINES

In addition to the beamline planned for the staging demonstration at the AWA facility (the main subject of this paper) we take a moment to discuss 2 other important staging beamlines (Table 1) in this section. These other beamlines are also based on dielectric wakefield acceleration but are only in the early planning stages at this moment.

The first beamline we label the *AWA Staging Demonstration* beamline and it is planned for a near term experimental demonstration in the AWA facility. In contrast to this near term demonstration experiment, the other two beamlines we consider in this paper are for long term consideration. We have made conceptual designs (strawmen) for the application of dielectric wakefield technology to both a High Energy Physics [1] machine

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Table 1: Staging Beamlines

Beamline	L (m)	p_0 (MeV/c)	$\Delta\theta$ (mrad)	$\Delta p_\perp$ (MeV/c)	t_{rise} (ns)	Stripline Voltage, Length	SW TDC Power, Length	TW TDC Power, Length
AWA Staging Demonstration	8	75	12.5	0.94	53	156 kV, 30cm	321 kW, 0.23m	3.8 MW, 0.3m
Dielectric TBA for LC	15	860	4.5	3.8	100	322 kV, 60cm	2.30 MW, 2.3m	17.4 MW, 0.57m
Collinear DWA for FEL	100	325	0.5	0.16	333	13 kV, 60cm	9.3 kW, 0.23m	0.3 kW, 1.9m

and a Light Source [7]. In Table 1, we label the former beamline the "Dielectric TBA for LC" and the later "Collinear DWA for FEL" where LC, DWA, and FEL, stand for, Linear Collider, Dielectric Wakefield Accelerator, and Free Electron Laser, respectively.

Quantitative estimates of the kicker requirements depend on the values of the separation between the drive bunches (Eq.1) the amplitude of the kick (Eq. 2). We assume that a horizontal displacement of Δx=50mm is required at the septum and R=4 for all 3 beamlines [6]. L=8m due to the limited space in the AWA bunker and the stage length, L, for the future beamlines were taken from the references [1,7]. Now, we can fill in column Δθ (Eq. 2) in the table. Similarly, given the bunch separation, 2L, (which is twice the separation listed in the table) we can fill in the entry for t_{rise} (Eq. 1).

FAST KICKERS TECHNOLOGY

In this section we consider possible kicker technologies that could be applied to the previously discuss staging beamlines. To meet the requirements of the kicker listed in Table 1, several technologies for the kicker are under investigation. To bend a beam with momentum p_0 by Δθ (Eq. 2) requires the deflecting element to impart transverse momentum,

$$\Delta p_\perp = \Delta\theta \cdot p_0 \tag{3}$$

Stripline Kicker

In our previous paper [6], we gave Eq. 4 for the bend angle due to a stripline kicker consisting of a pair of parallel plate striplines of length S and gap separation d,

$$\Delta\theta = \frac{eV_\perp}{T_0}\frac{S}{d} \tag{4}$$

where T_0 is the kinetic energy of the beam and the approximation $p_o c \approx T_0$ was used. In order to achieve the required amplitude of the bend (Δθ) we substitute into Eq.4 with S=30 cm, d=50 mm, and T_0 to fill in the required transverse voltages, $V_\perp$ in the table.

Examination of Table 1 shows that requirements of a stripline kicker for the AWA Staging Demonstration beamline are very difficult. This beamline would require the development of a very challenging power supply to provide a high voltage (156 kV) and fast risetime (50 ns) output. The requirements for a stripline kicker for the *Dielectric TBA for LC* are similarly difficult while the kicker for the *Collinear DWA for FEL* looks feasible. Given the relatively longer risetime of these later beamlines, once can reduce voltage requirement by increasing the stripline length, S. In addition, due to the higher energy the beam size would be smaller and the gap, d, can be reduced. These trade-offs will be the subject of future investigations.

SW TDC Kicker

We next consider a high Q, standing wave (SW), transverse RF deflecting cavity (TDC) for the fast kicker. While the SW TDC is known to be capable of very large transverse shunt impedance [6], the obvious problem is its slow time response due to its high Q. 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.

The Voltage Risetime, t_{fill}, is the time needed to fill to the SW TDC to full voltage. Given typical values for an L-band cavity, Q_0=1.5e4 and f_0=1.3 GHz, we find $t_{fill}=Q_0/\omega_0$=1.8μs, is much too slow in comparison to t_{rise}.

The Phase Shift Risetime was (naively) investigated to see if it was possible to change the phase of the SW TDC within the required risetime of Table 1. To test this, we performed a benchtop test (Fig. 2). In this circuit, the RF oscillator output was passed through a fast voltage). controlled phase shifter (ϕ), then a directional coupler, and finally into a SW cavity (Q_0=1.5e4 and f_0=1.3 GHz). A 6 GHz digitizing scope was used to monitor both the RF input (Ch. 3) and the cavity RF (Ch. 4). At time=0,

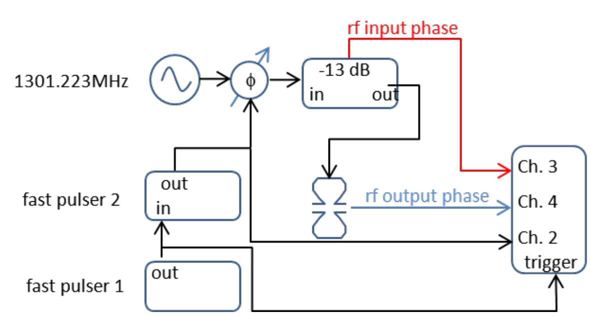

Figure 2: Setup to measure phase shift response time.

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fast pulser 1 triggered both the scope and *fast pulser 2*, which, in turn, triggered the voltage controlled phase shifter. The 1.3 GHz waveforms were captured and analysed offline with matlab. The phase response time of the SW cavity (*rf ouput phase*, Fig. 3) is exactly the same as the voltage response time. The authors of the paper do not know where else this result is stated but it seems obvious now.

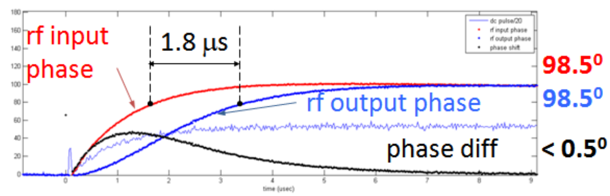

Figure 3: Phase response time result.

Fractional Harmonic SW TDC was previously shown [6] to require only modest power (321 kW, the previous paper [6] had a mistake) using the existing AWA (3 cell) TDC. However, this scheme does not scale well to multiple stages since the distance between the stages becomes very large as the number of stages increases and it's not feasible for the *future* beamlines. Nonetheless, this is possible solution for the AWA facility staging demonstration. Note that for the LC case in Table 1, the AWA TDC was scaled to be 10 times longer to reduce the power required by $\sqrt{10}$.

TW TDC Kicker

Another possibility is to use a traveling wave (TW) TDC. The SLAC LOLA [8] structure has v_g=10.89%c and transverse voltage,

$$V_\perp = \left(1.6 MV/m/MW^{1/2}\right) L\sqrt{P} \quad (5)$$

To satisfy the fill time of 53 ns (Table 1), the TW structure length must be L=0.3m ($\tau=L/v_g$). To generate V=156 kV (Table 1), the required power is therefore (Eq. 4) P=270 kW. For the LC, FEL beamlines, L=0.57m, 1.9m, and P=75 kW, 7 kW respectively.

The AWA power station risetime must be sufficient to drive the TW TDC. As a first check, we measured the risetime of the AWA klystrons (Thales, TV 2022X, 25 MW peak power, 10 µs max pulse duration, bandwidth 8 MHz (1 dB)). The risetime test was done by simultaneously monitoring the klystron rf input and rf output with a 6 GHz digitizing scope. The envelopes of the rf signals were obtained using a Hilbert transform in Matlab (abs(hilbert(*rf_signal*) and are displayed in Figure 4. From this we can see that the klystron input signal, low level rf, (LLRF) has a slow risetime but the klystron's output follows the input very closely, implying a fast risetime. To use this approach at the AWA would require an upgrade to improve the risetime of the LLRF.

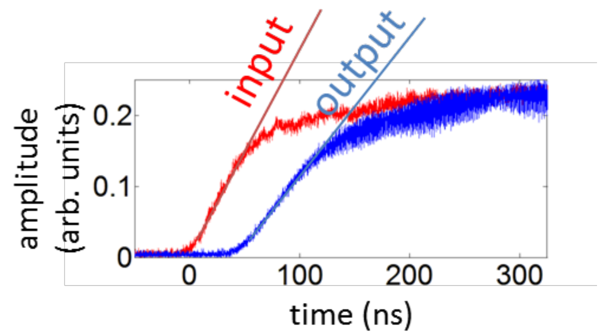

Figure 4: Klystron input (red) and output (blue) envelopes.

SUMMARY

Investigations into possible fast kickers for dielectric wakefield accelerators were made. We considered 3 beamlines, a near term beamline planned for the AWA staging demonstration and two conceptual beamlines, one for a linear collider and one for an FEL that may be built in the future. The demonstration experiment planned for the AWA bunker is especially challenging due to the limited space but both the TW TDC and fractional harmonic SSW TDC appear feasible.

REFERENCES

[1] W. Gai, J. G. Power and C. Jing, "Short-pulse dielectric two-beam acceleration," Jou. Plas. Phys. CJO 2012 doi:10.1017/S0022377812000037.
[2] Y. Nosochkov, L. Bentson, R. Erickson, M.J. Hogan, N. Li, "Optics Design for FACET," PAC09, Vancouver, BC, Canada, WE6PFP080 (2009).
[3] G.V.Sotnikov et al. "Analytical and Numerical Investigation of a Coaxial Two-Channel Dielectric Wakefield Accelerator," PAC09, Vancouver, BC, Canada, WE6RFP086.
[4] M. Conde et al., "Upgrade of the Argonne Wakefield Accelerator Facility (AWA) and Commissioning of a New RF Gun For Drive Beam Generation," see these proceedings, PAC'11.
[5] W. Gai, "Multi-stage wake-field accelerator," AIP Conference Proceedings Vol. 193 (1989).
[6] J. G. Power et al., "Staging in Dielectric Two Beam Wakefield Accelerators," IPAC'11, San Sebastian Spain, WEPZ015.
[7] C. Jing, J.G. Power, and A. Zholents, "Dielectric Wakefield Accelerator to Drive the Future FEL Light Source," APS Light Source Note, LS-326, (2011); http://www.aps.anl.gov/Science/Publications/lsnotes.
[8] R. Akre, L. Bentson, P. Emma, P. Krejcik, "A Transverse RF Deflecting Structure for Bunch Length and Phase Space Diagnostics," PAC01, Chicago, IL, USA, WPAH116 (2001).