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STAGED TWO BEAM ACCELERATION BEAM LINE DESIGN FOR THE AWA FACILITY

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Abstract

Two beam acceleration is a candidate for future high energy physics machines and FEL user facilities. This scheme consists of two independent electron accelerators operating synchronously. High-charge, 70 MeV bunch trains in the drive accelerator are injected from the rf photoinjector into decelerating structures to generate a few hundred MW of rf power. This rf power is transferred through an rf waveguide to accelerating structures that are used to accelerate the witness beam in an otherwise independent second accelerator and beam line. Staging refers to the sequential acceleration (energy gain) in two or more structures on the witness beam line. A kicker was incorporated on the drive beam line to accomplish a modular design so that each accelerating structure can be independently powered by a separate drive beam. Simulations were performed in OPAL to model the two beam lines. Beam sizes at the center of the structures was minimized to ensure good charge transmission. The resulting design will be the basis for proof of principle experiments that will take place at the Argonne Wakefield Accelerator (AWA) facility.

AWA FACILITY

The AWA facility houses two rf photoinjectors operating at 1.3 GHz. The bunch charge is routinely adjusted depending on the requirements of the experiments downstream of the photoinjector. Typical operating charges are 1, 4, 10, and 40 nC. While these are the most common operating modes, other charges have been requested and provided depending on the experiment. Recent experiments include emittance exchange [1], high gradient structure tests [2], thermal emittance measurements [3], and two beam acceleration [4] (TBA), which is the subject of this proceeding.

TWO BEAM ACCELERATION LAYOUT

The AWA facility lends itself well to TBA experiments due to the close proximity of both operational photoinjectors. They are located in the same bunker about two meters apart. This distance slightly varies along the beam lines. For the remainder of this paper, we will refer to the low charge beam line as the "witness" line, and the high charge beam line is called the "drive" line. While the charge on each line can be varied, for TBA experiments, the witness line is operated at 1 nC and the drive line is operated at 40 nC.

The planned TBA layout is shown in Fig. 1. The drive line has six accelerating cavities with a maximum beam energy of 70 MeV. The witness line has one accelerating cavity with a maximum beam energy of 15 MeV. The guns are located at opposite ends of the bunker and the propagation direction of the beam lines are opposing. The witness line is operated in single bunch mode, and the drive line supplies high charge bunch trains. The planned experiments will include trains of eight bunches with about 40 nC in each bunch.

The kicker will ensure that one bunch train is supplied to each stage. This allows for more energy transfer in stage 2. If the same bunch train supplies both stages [4], the amount of available energy for stage 2 would be decreased by the amount of energy deposited in stage 1. This would cause unequal energy gain in each stage. After passing through the kicker, the high charge bunch trains are guided to Power Extraction and Transfer Structures (PETS) downstream. These decelerating structures extract power from the bunches through wakefield generation. The structures take advantage of superposition and allow the wake from each bunch to combine with the others. The high power pulse generated by the combination of wakes is transfered through a waveguide to the witness line. There are two decelerating stages on the drive line, and two corresponding accelerating sections on the witness line. The accelerating structures, ACC_1 and ACC_2, are only powered by the PETS on the drive line. There is no external power source.

Stage 1

The first accelerating stage refers to portions of the beam line that include ACC_1 and $PETS_1$. This is the straight through portion of the drive beam line. The first bunch train passes through the kicker when it is unactivated, i.e. no pulse and no field are present. The bunch train will then arrive at the quadrupoles before $PETS_1$. Focusing will ensure maximum transmission of the 40 nC bunch train through $PETS_1$. Integrated Current Transformers (ICT's), are located before and after all PETS and ACC structures to monitor the transmission.

Although not shown in Fig. 1, a spectrometer will be located at the end of the line for energy measurments. Energy loss in the bunch train will serve as a way to infer how much power was deposited in $PETS_1$. Energy measurements in combination with rf probe measurements in the transfer waveguide and ACC_1, will be used to calculate losses in the stage and gradient.

Stage 2

Stage 2 includes ACC_2 and $PETS_2$. After the first bunch train passes the kicker and goes on to $PETS_1$, the kicker

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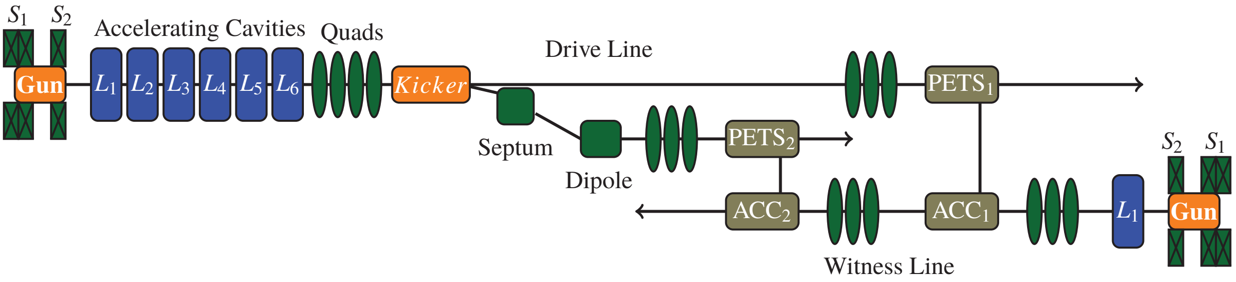

Figure 1: TBA beam line layout at the AWA. The arrow at the end of each line indicates what direction the beam is traveling. PETS stands for Power Extraction and Transfer Structure, and ACC stands for Accelerating structure. The subscript index on each structure refers to which stage the structures belong to, first or second stage.

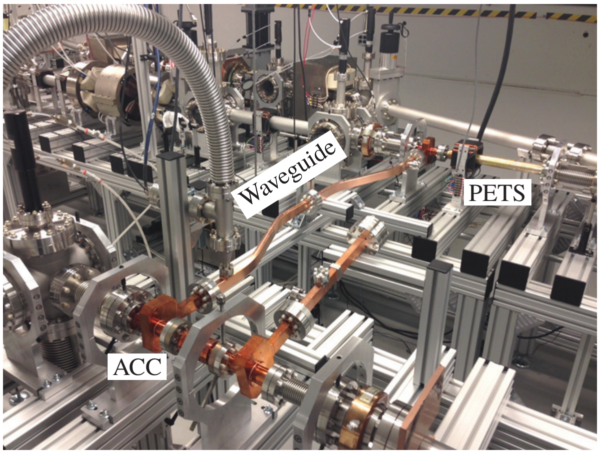

Figure 2: Example of a TBA stage at the AWA. This picture was taken during a TBA experiment [4].

will be pulsed. The second bunch train will be directed to the bent beam line on the drive side. Meanwhile on the witness side, the same bunch that was accelerated in stage 1 will arrive at stage 2, receiving a second increase in energy. Successful energy gain in both stages is key to demonstrating staged TBA. A second spectrometer will be located at the end of the bent beam line. There will also be another set of spectrometers on the witness line.

SYNCHRONIZATION

The rf power generated on the drive line must reach the accelerating structures as the witness beam is arriving. This requires detailed understanding of the laser trigger, bunch train spacing, beam travel times, rise time of the rf pulse generated in the PETS, travel time of the pulse in the waveguide, and the fill time needed in the accelerating structures. While implementing this level of synchronization is not trivial, it is possible, and has been demonstrated in previous experiments at the AWA [4].

To start, a 248 nm ultraviolet (UV) laser is pulsed at the same repetition rate as the beam line. This is either 1, 2, or 5 Hz. The full width half maximum (FWHM) of the laser can be varied from 1.5 ps to 10 ps. Depending on the FWHM, the duration of the UV pulse ranges from 1 to 3 degrees of the 1.3 GHz rf frequency.

Electron bunches in both the drive and witness line originate from the same UV laser pulse. A network of UV optics and splitters deliver one laser pulse to the witness gun, and a pulse train to the drive gun [5]. Each individual bunch is generated within one period (T) of the rf frequency; 769 ps. This brings the length of an eight bunch train to 7 T or about 5.4 ns. Spacing between the bunches allows the wake from previous bunches to start filling the PETS before the wake from the next bunch is introduced.

The drive bunch train must travel a longer distance to reach $PETS_1$ than the distance the witness bunch must travel to reach ACC_1. The difference in travel time is accounted for by adding an optical delay to the UV optics preceding the witness gun. Once the rough timing is adjusted with the optics, fine timing is adjusted by calculating the rise and fill times of the PETS and accelerating structures. The overall timing depends on two key events. When drive bunch train 1 reaches $PETS_1$, the witness bunch must be near the entrance of ACC_1. Next, when drive bunch train 2 reaches $PETS_2$, the same witness bunch that was accelerated in ACC_1, should be approaching ACC_2. If the timing is correct, there will be sequential energy gain in both stages.

KICKER

A kicker was specifically fabricated for this experiment. The initial design was adapted from work done at Indiana University [5, 6]. The plates were lengthened to increase the beam deflection angle and the gap adjusted based on beam size simulations and mechanical constraints at the AWA. The design specifications and final kicker parameters are shown in Table 1. The plates will be operated in differential mode, to get the highest field possible from the available pulsar.

After fabrication, a high voltage test was performed to ensure the electrical feedthroughs were sound. Special thanks to the Power Systems group at the Advanced Photon Source (APS) for testing the kicker in one of their rf cages, see Fig. 3. A high voltage 60 Hz source was used to probe one blade of the kicker at a time. Both sides performed well, with one blade showing slight discharge at 8 kV RMS, and the

Table 1: Final Kicker Parameters

Parameter	Value
Charge	40 nC
Beam Energy	70 MeV
Angle	2°
Gap Between Plates	40 mm
Length of Plates	500 A
Pulsar Voltage	±24 kV
Field Rise Time	3 ns
Field Duration	12 ns

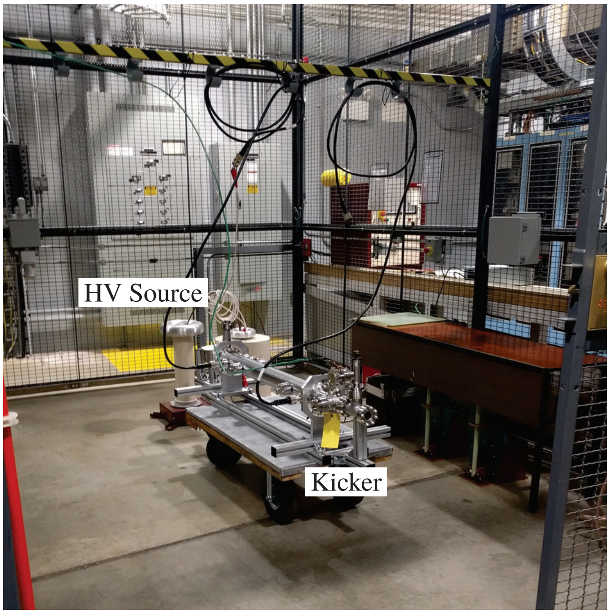

Figure 3: Kicker in high voltage (HV) testing cage at the Advanced Photon Source.

other showing no discharge up to 9 kV RMS (the limit of the source). These results are in line with other kickers designed and tested at the APS [7].

ONGOING OPTIMIZATION

While the number of optics elements and their general locations is known, there are still many free parameters that are not determined by that information alone. The strength of each magnet, the phase in each cavity, and the laser profile can all be freely adjusted. This leads to a high dimensional optimization problem. The parameters on the drive line are further complicated by strong space charge forces and bending elements (kicker, septum, dipole).

A first round multi-objective optimization of the drive line has been performed using the built in genetic algorithm (GA) in OPAL-T [8]. These simulations included the gun and all elements leading up to the entrance of the septum, as shown in Fig. 1. The objective was to optimize the beam size, emittance, and energy spread before the kicker. Simulation parameters are shown in Table 2. The resulting Pareto fronts before the kicker at $Z = 16.5$ m, and after the kicker at $Z = 18.5m$ are shown in Fig. 4. Results so far indicate that both drive trains can be transported successfully. A detailed description of the optimization work will be published soon.

Table 2: Drive Line Simulation Parameters

Parameter	Fixed Values	Optimization Values
Charge	40 nC	–
Laser Radius	9 mm	–
Gun Gradient	65 MV/m	–
Laser FWHM	–	$1.5\,\text{ps} \leq F \leq 10\,\text{ps}$
Gun Phase	–	$-30° \leq \phi_g \leq 0°$
S_1	–	$350\,\text{A} \leq B \leq 500\,\text{A}$
S_2	–	$170\,\text{A} \leq M \leq 260\,\text{A}$
Quads	–	$-8\,\text{Tm}^{-1} \leq M \leq 8\,\text{Tm}^{-1}$

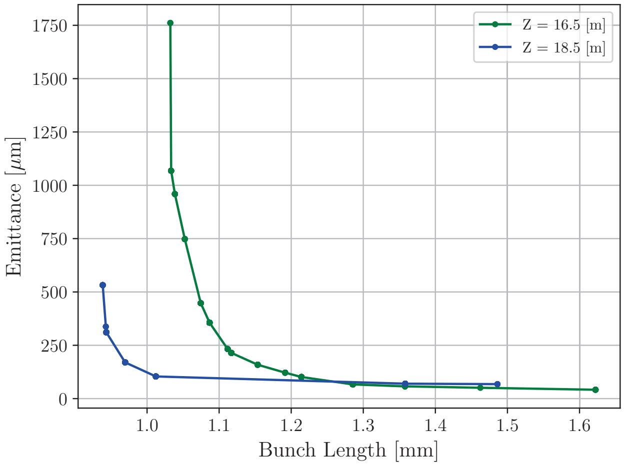

Figure 4: Comparison of Pareto fronts before ($Z = 16.5m$) and after ($Z = 18.5m$) the kicker.

CONCLUSION

The TBA layout for upcoming experiments at the AWA facility is approximately decided. A fast rise time kicker was designed and fabricated for this experiment. A successful high voltage test was preformed at the Advanced Photon Source. Initial optimization work has been done to determine optics parameters for the high charge drive line. Additional design work and optimization studies will be done to finalize the optics further downstream.

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