DRIVE GENERATION AND PROPAGATION STUDIES FOR THE TWO BEAM ACCELERATION EXPERIMENT AT THE ARGONNE WAKEFIELD ACCELERATOR

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Abstract

Simplified staging in a two beam accelerator (TBA) has been accomplished at the Argonne Wakefield Accelerator (AWA) facility. This layout consists of a drive beamline and witness beamline operating synchronously. The drive photoinjector linac produces a 70 MeV drive bunch train of eight electron bunches (charge per bunch between 5-40 nC) that pass through decelerating structures in each TBA stage. The witness linac produces an 8 MeV witness bunch that passes through the accelerating structures in each TBA stage. Recent effort has been focused on improving the uniformity of the UV laser pulses that generate the bunch trains.

Current work at the AWA is focused on the transition from simplified staging to full staging. A kicker will be designed and installed to direct bunch trains to one TBA stage only. Preliminary calculations and simulation results are presented.

MOTIVATION

The next generation of accelerators dedicated to High Energy Physics (HEP) will be of the TeV scale. Reduction in the size and cost of such machines is key to their feasibility, and can be accomplished through accelerator technology R&D. Investigation into a high gradient candidate for future HEP machines is underway at the Argonne Wakefield Accelerator (AWA) facility [1]. AWA plans to develop a short pulse, two-beam acceleration (TBA) scheme using dielectric Power Extractors and Transfer Structures (PETS) and Dielectric Loaded Accelerating structures (DLA). The goal of AWA is to demonstrate a gradient of 250 MV/m, using this TBA dielectric scheme. The AWA is currently preforming proof of concept experiments in support of short pulsed TBA, and has accomplished staging of metallic TBA.

DRIVE BEAM GENERATION

The drive beamline is the power source that supplies rf to the accelerating structures on the witness beamline. In order to transport the maximum power possible, bunch trains are generated and propagated down the drive line toward the TBA stages. Power is extracted from the drive train using metallic PETS (decelerating structures), and the power is transferred to the accelerating structures using waveguide. In order to generate the drive trains needed for this process, a UV laser pulse is split by four 50/50 optical splitters into trains of eight pulses. See Fig. 1 for optics configuration. Optical delay lines (two mirrors) near each splitter separate pulses by extending the distance that each pulse travels. Each delay line length is a multiple of the repetition rate wavelength, 1.3 GHz. This produces a separation of 1 λ between each UV pulse.

Figure 1: Multisplitter optics table. The drive gun is located to the right of this table.

Ideally, to extract maximum power from the train, each electron bunch in the drive train would have the same amount of charge. However, that would require perfect 50/50 splitters. The previously installed splitters were rated at a tolerance of ± 5%, and a joule meter was used to measure the laser energy in pulses one through eight. The results indicated the ratio of reflection to transmission for each splitter was R/T ≈ 45/55. This caused an uneven laser intensity distribution, because the bunch intensity depends on the path it takes through the multisplitter optics. For example, laser pulses that are reflected on multiple splitters have the lowest intensities (when using the ± 5% splitters). Consider the path of laser pulse four as shown in Fig. 2. The pulse is transmitted through splitters 1, 2, and 4, but is reflected by splitter 3. Therefore, this bunch had a fairly high intensity, because it was transmitted multiple times. This trend was reflected in the electron bunch trains generated in the gun. In the worst case, the laser intensity of bunch six was 50% that of bunch one, see Fig. 3.

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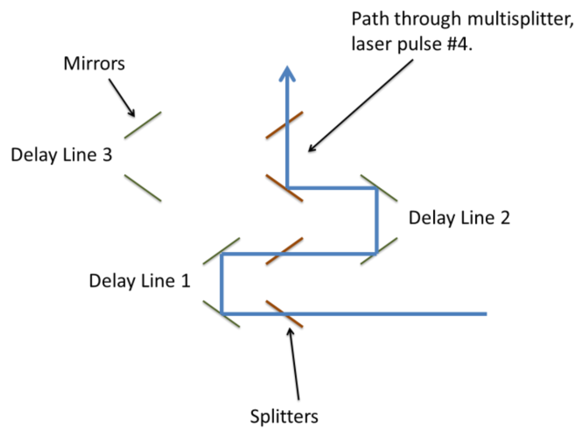

Figure 2: Simplified drawing of multisplitter optics layout, and path of laser pulse four through the multisplitter.

To improve the intensity distribution, splitters with a tolerance of ± 3% were purchased, installed, and the laser energy was measured. The quality of the splitters was near tolerance again, and the bias leaned toward the reflection, R/T ≈ 53/47. With the bias now reversed, the trend in intensity distribution is also reversed, see Fig. 3. The possibility of using a combination of splitters from the ± 3% and ± 5% sets was explored. Using a python script to compare all possible combinations, it was determined that using only ± 3% splitters would result in the lowest variation in the train intensity.

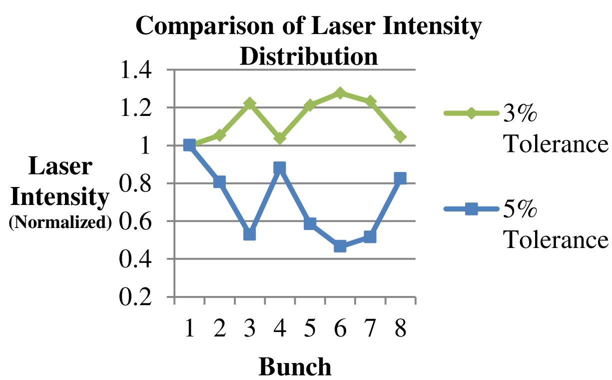

Figure 3: Laser intensity distribution of 50/50 splitters with tolerance of ± 5% and ± 3%.

SIMPLIFIED STAGING LAYOUT

The current layout at the AWA includes two beamlines (the drive and witness), and two metallic TBA stages with one structure each. Figure 4 shows a simplified version of the layout. In this scheme, TBA stages are installed sequentially on the drive beam line. Each bunch train travels through two TBA stages. This causes a loss of energy in the first train, as it passes by the PETS in the second TBA stage. If more stages were installed in the simplified version, the losses in the drive beam would very high, and power output in the later PETS would be low. The AWA will address this issue by switching to full staging.

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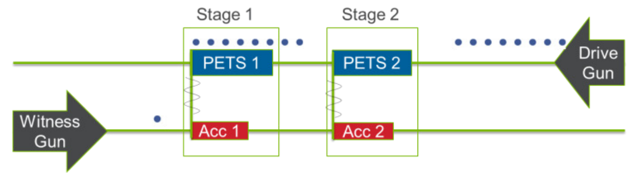

Figure 4: Simplified TBA layout. This scheme is currently installed at the AWA.

FULL STAGING LAYOUT

It is the goal of AWA to accomplish full staging in the next 3 years. In this layout, the bunch train generation will remain the same; however, the beamline will be improved. Stages will be separated onto individual beamlines branching from the drive line, and a kicker will direct each bunch train to one stage only.

The full staging layout will consist of four PETS and four accelerating structures, as shown in Fig. 5. Each stage will contain two structures. Completion of this project would include installation of dielectric PETS, dielectric accelerating structures, and the design, simulation, and installation of a kicker.

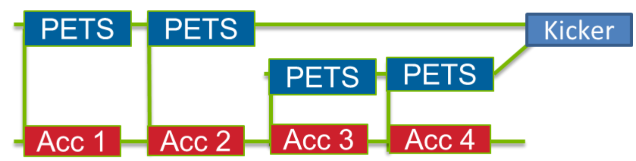

Figure 5: Full staging TBA layout. This beamline will be installed after kicker design and fabrication is complete.

KICKER DESIGN

A kicker, also commonly called a pulsar, refers to a pulsed power supply feeding voltage and current to a set of parallel plates located inside the beam pipe. The purpose of this device is to achieve a quick deflection of the beam; in this case, to route each bunch train to corresponding decelerators. Using a kicker to separate the drive trains will increase the charge supplied to the dielectric PETS by avoiding power loss in the other stages. The increase in charge supplied to each stage will then increase the resulting power output.

The power supply that will be used for the kicker has a fast rise time of 20 ns, and a high voltage rating of ± 35 kV. A kicker plate design implemented by Indiana University (IU) is being adapted to fit the requirements at the AWA [2]. Current design parameters include a gap of 30 mm and plate length of 0.6 m, which would result in a 2° kick for a 70 MeV beam. Using the kicker plates and power supply alone, the angle provided by the kicker can be calculated from the induced electric field between the plates [2].

$$\theta_E = \frac{VL}{hT}$$

Where V is the power supply voltage, 70 kV in this case, L is the length of the kicker, h is the kicker gap, T is the kinetic energy of the beam, and the resulting angle will be in radians. However, if the kicker plates are terminated in a 50 Ω load, a steady state current will be induced on the kicker plates in addition to the voltage from the power supply. Using this technique, a TEM mode will exist between the plates. This allows for an equal kick from both the electric and magnetic field. Calculation of the magnetic field kick depends on the field strength, kicker length, and beam energy [3].

$$\theta_B = \frac{BL}{B\rho}$$

Where B is the magnetic field strength, L is kicker length. $B\rho = 3.33564\,T$ has the units of GeV-Tesla and is an accelerator physics term that can be found in text such as Wiedemann [3]. Substituting $B = \frac{E}{c}$ and $E = \frac{V}{h}$, we can see that the two angles are nearly equal, $\theta_E \approx \theta_B$. Therefore, by terminating the kicker plates you can get double the kick per a given power supply. After a preliminary kicker design and angle was chosen, simulations began using the particle in cell code OPAL-T.

These simulations focused on determining whether or not 30 mm is a feasible kicker gap. The drive beam was simulated in the gun, six cavity linear accelerator, three quadrupoles (triplet), and a drift section. These elements will precede the kicker when installed. Table 1 shows a summary of beam input parameters used for these simulations.

Table 1: OPAL-T Input Parameters

Parameter	Value
Charge	40 nC
Laser Radius	6 mm
FWHM Laser	2 ps

In Fig. 6, the triplet was set to a ratio of 1 T focusing and 1.98 T defocusing to acquire a round beam near the expected entrance of the kicker. This shows a kicker gap of 30 mm may be acceptable, since the 6 σ beam size is about 16 mm. While this result is encouraging, further simulations and analysis are needed to determine if these kicker parameters are optimum.

Future simulations will incorporate an electromagnetic field map to model the kicker and test the effects on the beam dynamics. The final simulation models will also incorporate collective effects such as wakefields and coherent synchrotron radiation (CSR). Space charge is already incorporated into every simulation.

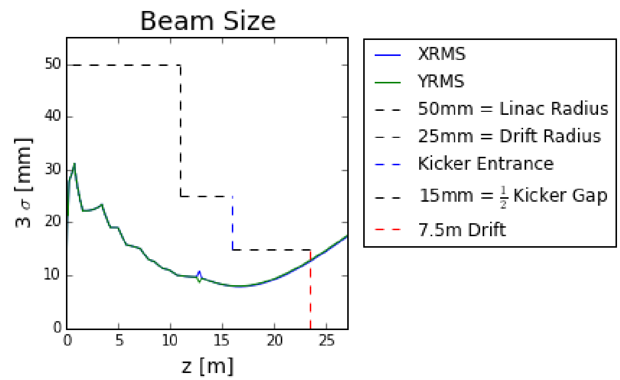

Figure 6: Beam size simulation results on the drive beamline. Beam size is well below the kicker gap width.

FUTURE WORK

The current UV laser splitters will remain installed. Other laser work will focus on enclosing most of the laser path in vacuum. Currently, the laser travels several meters in air, which degrades the laser quality.

Future work towards full staging will include simulations of the drive line and kicker including wakefield effects and beam loading. An optimum kicker design will be picked based on beam dynamics simulations and physical constraints. Once the kicker design is finalized it will be installed in the full staging layout and used to direct bunch trains to separate stages.

CONCLUSION

The overall laser intensity distribution was improved by using splitters with a tighter tolerance (± 3% vs. ± 5%). A kicker is currently being designed for the next phase of two beam acceleration at the AWA, full staging. A kicker designed by IU is being optimized to achieve a 2° kick for a 70 MeV beam. Preliminary simulations show this angle may be possible, but further beam dynamics simulations are needed to confirm this.

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