

HIGH-CHARGE-SHORT-BUNCH OPERATION POSSIBILITY AT ARGONNE WAKEFIELD ACCELERATOR FACILITY

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Abstract

The Argonne Wakefield Accelerator (AWA) drive RF photoinjector linac was designed to generate a 75 MeV high charge bunch train of up to 100 nC per bunch. Recently we installed a double dog-leg type emittance exchange beam line and studies are now underway of two options to use a part of this beamline for the bunch compression. In one option, we introduce a chicane and in the other we use a single dog-leg. Simulations have been carried out to find the minimum bunch length for a range of charges (1- 40 nC) and the emittance growth due to coherent synchrotron radiation. We present GPT simulation results to show the high-charge-short-bunch operation possibilities at the AWA facility.

DOWNSTREAM BEAM LINE OF ARGONNE WAKEFIELD ACCELERATOR

The Argonne Wakefield Accelerator (AWA) has two main beam lines that are used to generate a drive beam and a witness beam for the demonstration of two beam acceleration (TBA) [1]. The drive linac consists of an L-band photocathode gun followed by six RF accelerating cavities to generate a 75 MeV beam. The main experimental beamline exits a straight from the drive linac into two device under test areas with a spectrometer at the end. Recently, we installed a double dog-leg emittance exchange (EEX) beam line that has two identical dog-legs [2].

We are comparing two options for adding a magnetic bunch compressor to the AWA facility (Fig. 1): a chicane vs a dog-leg compressor. The first option, the chicane, adds a dipole to the straight ahead beamline while the second option, the dog-leg compressor, uses the first dog-

leg of the EEX beamline. In the rest of paper, we present the results of the bunch compression achieved and the corresponding emittance growth for these beamlines

BUNCH COMPRESSION AND EMITTANCE GROWTH

A strong bunch compression is predominantly limited by the emittance growth in both the chicane and the single dog-leg (path “A” and path “B” in Fig. 1). Our GPT simulations include a 3D space-charge routine [3] and 1D CSR routine [4]. Table 1 shows the parameters of the EEX beam line and the incoming beam parameters at the AWA. The incoming beam energy was varied while the linac phase was changed to control the longitudinal chirp. We simulated incoming charges of {1, 5, 10, 20, 30 and 40 nC} with the gun launch phase set to 50 deg (maximum energy) and a fixed laser pulse length of 8 ps FWHM. These are the nominal operation parameters for the AWA drive gun.

Table 1: Beam Line Specification

Beam line parameters	Value	Unit
Bending angle	20	deg
Drift length in the dog-leg	2.0	m
Drift length between two dog-leg	1.5	m
η (dispersion of dog-leg)	0.9	m
ξ (momentum compaction of dog-leg)	0.3	m
Incoming beam parameters	Value	Unit
Maximum beam energy	75	MeV
Charge	0.1-100	nC
Bunch length	0.3-2.0	mm

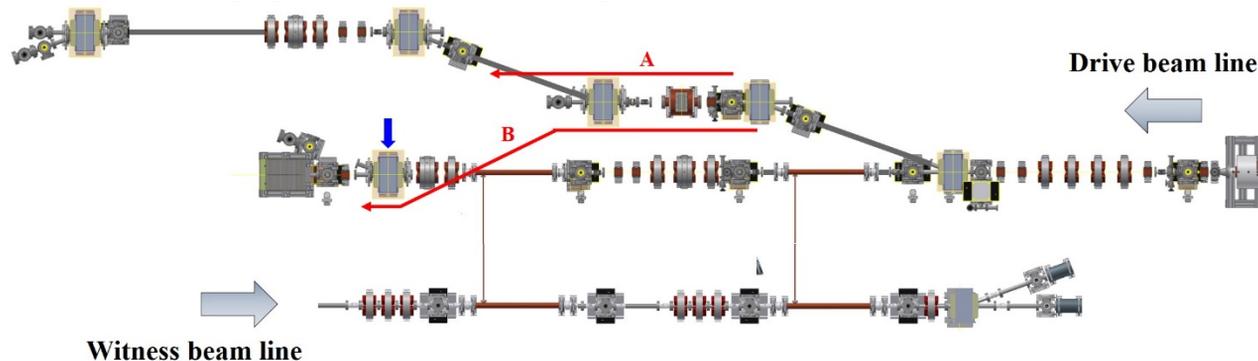


Figure 1: The downstream beam line configuration of the AWA. The dipole magnet indicated by the blue arrow is added for the chicane.

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The linac phase offset used in the simulations was set to generate the appropriate longitudinal chirp for each beam line: $-1/\xi$ for the dog-leg and $-1/2\xi$ for the chicane. The bunch length and the emittance after both beam lines with different linac phase offsets are shown in Fig. 2 and Fig. 3. Although the minimum and maximum of the emittance and the bunch length are different for each charge, they follow the same trend marked ‘a’, ‘b’, ‘c’, and ‘d’ in Fig. 2 (a) and (b).

The beams passing each dipole magnets generate a CSR which increases the emittance from its original value (pattern ‘a’). As a charge grows up, the CSR make a more emittance growth and the pattern ‘a’ has a bigger separation between the original emittance and the minimum emittance after the beam line; see Fig. 3. In the case of the dog-leg, the dispersion leads to the emittance growth of $\eta\sigma_\delta$. Since the correlated energy spread before the compressors depends on the linac phase offset, the

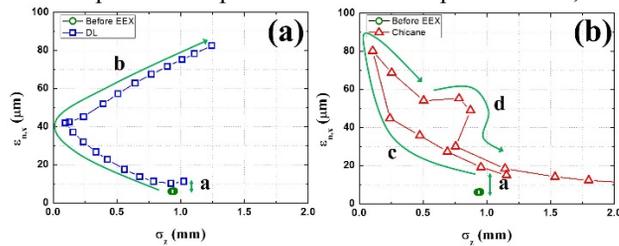


Figure 2: The change of the bunch length and the emittance of 1 nC beam at the downstream of the dog-leg (a) and the chicane (b). The linac phase offset is scanned by 1 degree step.

emittance after the dog-leg increases (pattern ‘b’). The chicane compressor has an emittance growth coming from the CSR. Since the bunch length in the dipole magnets depends on the initial longitudinal chirp, the emittance continuously increases due to the CSR as the chirp goes to $-1/2\xi$ (pattern ‘c’). After the chicane generates the shortest bunch length, an elongated bunch due to the over-compression reduces the emittance smoothly. When the initial longitudinal chirp is close to $-1/\xi$ which is the full compression condition for the dog-leg, a strong CSR through the third bending magnet increases the emittance and the bunch length (pattern ‘d’).

Figure 3 shows the bunch length and the emittance after each compressor with different charges and different linac phase offsets. The four trends in Fig. 2 appear clearly in the Fig. 3 well. Even for the 1 nC case, CSR due to the third and fourth dipole generates a larger emittance growth than the dispersion at the full compression conditions. For the low charges, the linac phase offset for the full compression of the chicane is the half of the offset for the dog-leg. As the incoming charge increases, larger negative chirp is required to compensate the CSR effect in the chicane. In the case of 40 nC, the linac phase offset of -28 deg and -22 deg generate the minimum bunch length for the dog-leg and the chicane respectively. The closer minimum bunch length conditions makes the larger gap between the chicane and the dog-leg.

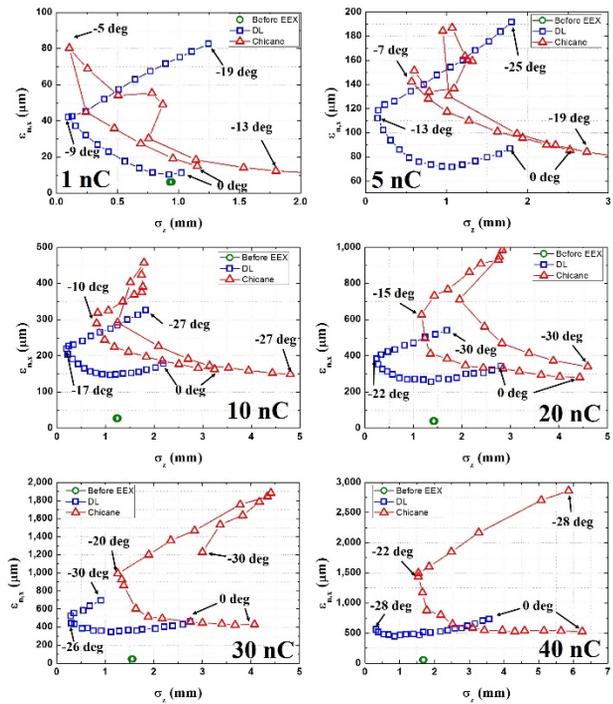


Figure 3: The change of the bunch length and the emittance after the dog-leg (blue) and the chicane (red) for different charges.

Figure 4 shows the compression ratio and the transverse emittance after compressors at the minimum bunch length condition. As can be seen in Fig. 2 and Fig. 3, present AWA compressors generate a considerable CSR. Especially, the chicane make a higher emittance growth than the dog-leg which even includes a residual dispersion. In terms of the compression ratio and the transverse emittance, the dog-leg compressor is better than the chicane compressor in the AWA operating condition.

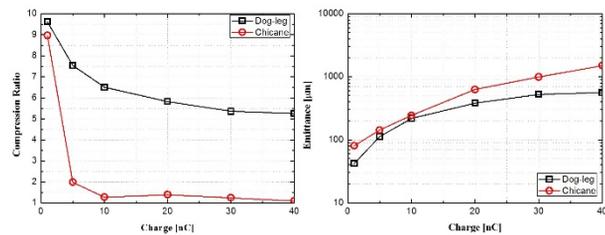


Figure 4: The compression ratio as a function of incoming charges at the minimum bunch length condition (left). The emittance after the beam line with the minimum bunch length condition (right).

The dog-leg compressor could compress the bunch length of the 20 nC beam to 0.3 mm. The corresponding transverse emittance at the exit is 400 μm . Since the rms beam size after drift of length L can be reduced up to $L\varepsilon/\sigma$ where ε is the unnormalized transverse emittance, and σ is the rms beam size, the beam size can be reduced to 660 μm if L is 1 m, σ is 5 mm, and the beam energy is 60 MeV. Also, the rms beam size is less than 1 mm for ~ 50 cm long distance.

Although the dog-leg compressor provides a high-charge-short-bunch beams, its emittance is not small enough to use this beam for the high frequency wakefield generating structures which have a small aperture (<1 mm). To enhance the emittance, we consider to apply the collimator after the dog-leg.

DOG-LEG WITH BERYLLIUM WINDOW AND COLLIMATOR

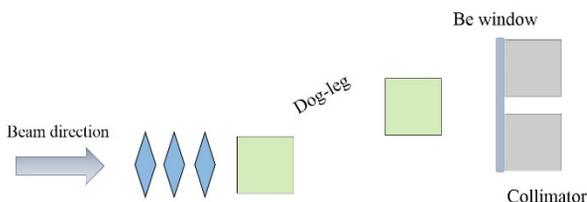


Figure 5: The beam line configuration for the emittance reduction using collimator.

Figure 5 is the configuration using the dog-leg compressor with a collimator for the emittance reduction. The Beryllium (Be) window is applied to preserve the high vacuum on the other side of the drive beamline. Since the dog-leg generates the horizontal-longitudinal correlation, the aperture and the length of the collimator, and the input beam condition control not only the final emittance and the remained charge but also the bunch length. If the initial transverse components are minimized by quadrupoles before the dog-leg, the collimator selects the time slice of the initial beam.

The concerned beam parameters were tracked using the GPT simulation. The linac phase off set was scanned and the result is displayed in Fig. 6. The collimation was applied to the horizontal direction only because the dispersion does not affect vertical properties. The aperture diameter was set to 2 mm and the length of the collimator was 1 cm. Since the Be window could generate a huge emittance growth due to the multiple scattering [5], we implemented the multiple scattering formula [6] to the GPT. The thickness of the Be window was chosen to 8 μm which is the minimum thickness we can make to minimize the emittance growth.

Figure 6 shows the evolution of the bunch length, charge and emittance along the whole beam line. The beam is longitudinally compressed through the dog-leg. The final bunch length is 0.33 mm while the initial bunch length is 1.43 mm. The charge of the beam is reduced to 1.3 nC from 20 nC due to the collimation. The transverse emittance of the beam was 34.9 μm before the dog-leg and reduced to 19.5 μm due to the collimation.

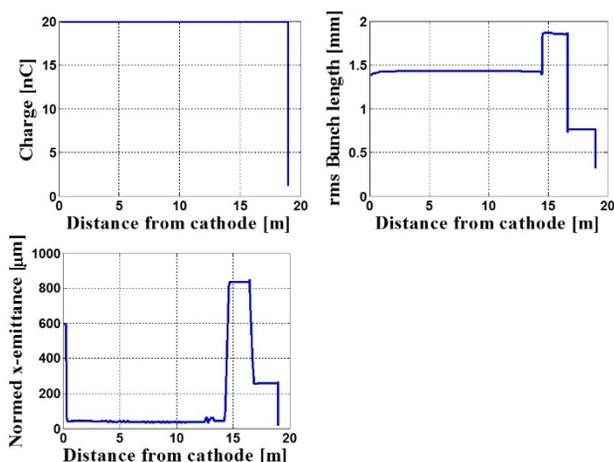


Figure 6: The evolution of beam parameters along the entire beam line.

CONCLUSION

In general, the single dog-leg compressor leaves a residual dispersion at its exit which generates a transverse-longitudinal correlation and thus increases the transverse emittance. While the chicane has no residual dispersion, it has a comparable emittance growth to the dog-leg due to the chicane's strong CSR coming from the large bending angle at the high charge. The dog-leg compressor at AWA can generate high-charge-short-bunches. For example, 20 nC beam can be compressed to 0.3 mm with the transverse emittance of 400 μm . To enhance the emittance, we simulated new scheme using the Be window and collimator and achieved 0.33 mm long bunch with the charge of 1.3 nC and the emittance of 19.5 μm . In the future, we will explore how to enhance the ratio of the charge to the emittance.

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