

# DEMONSTRATION OF CURRENT PROFILE SHAPING USING DOUBLE DOG-LEG EMITTANCE EXCHANGE BEAM LINE AT ARGONNE WAKEFIELD ACCELERATOR

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## Abstract

Emittance exchange (EEX) based longitudinal current profile shaping is the one of the promising current profile shaping technique. This method can generate high quality arbitrary current profiles under the ideal conditions. The double dogleg EEX beam line was recently installed at the Argonne Wakefield Accelerator (AWA) to explore the shaping capability and confirm the quality of this method. To demonstrate the arbitrary current profile generation, several different transverse masks are applied to generate different final current profiles. The phase space slopes and the charge of incoming beam are varied to observe and suppress the aberrations on the ideal profile. We present current profile shaping results, aberrations on the shaped profile, and its suppression

## ZERO-DIAGONAL CHARACTERISTIC AND BUNCH SHAPING

When the beam travels inside emittance exchange (EEX) beam line, it experiences the exchange of whole transverse and longitudinal properties. As a result of property exchange, transverse-to-longitudinal emittance exchange happens. In terms of linear transfer matrix, this property exchange provides very interesting matrix format: zero-diagonal. Eq. 1 shows the simplified version of EEX beam transfer matrix in [1].

$$\begin{pmatrix} x_f \\ x'_f \\ z_f \\ \delta_f \end{pmatrix} = \begin{pmatrix} 0 & 0 & A' & B' \\ 0 & 0 & C' & D' \\ A & B & 0 & 0 \\ C & D & 0 & 0 \end{pmatrix} \begin{pmatrix} x_i \\ x'_i \\ z_i \\ \delta_i \end{pmatrix}. \quad (1)$$

If the EEX condition ( $1 + \kappa\eta = 0$ ) is satisfied, the transfer matrix of EEX beam line has zero-diagonal. In terms of longitudinal bunch shaping. This zero-diagonal is the key feature. Since the main interest for shaping is  $z_f$ , it can be rewritten as,

$$z_f = Ax_i + Bx'_i. \quad (2)$$

For the low emittance beam, one can imagine a quasi-linearity between  $x_i$  and  $x'_i$  (i.e.  $x'_i = Sx_i$ ). By this quasi-linearity, Eq. 2 can be simplified even further,

$$z_f = (A + BS)x_i. \quad (3)$$

This relation clearly shows the final longitudinal profile becomes a linear scale of initial horizontal profile. In other words, we can generate any current profile if we can generate it on the horizontal space.

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## EMITTANCE EXCHANGE BEAMLINE AT ARGONNE WAKEFIELD ACCELERATOR FACILITY

Double dogleg emittance exchange (EEX) beam line was installed at Argonne Wakefield Accelerator facility in 2015. This beam line was designed to demonstrate the generation of arbitrary current profile [2] and slope control method to mitigate the second order aberrations [3]. Bending angle and the dipole to dipole distance are chosen to reduce the power requirement at TDC [4] and generate reasonably strong aberrations for the measurement (See Table. 1). For the transverse manipulation, four quadrupoles are introduced in front of EEX beam line, and these quadrupoles controls both beam size and slope at the same time. For the arbitrary current profile generation, several different 250 micron thick tungsten mask were prepared [5]. These masks were used to generate various initial horizontal profiles during the experiment.

5 nC Electron bunch was generated using homemade Cs<sub>2</sub>Te cathode [6], and it was accelerated by L-band cavities up to 48 MeV. Longitudinal chirp of the electron bunch was controlled using the phase in the accelerating cavities. Nominal electron beam conditions are given in Table 1.

Table 1: Beam line and input beam parameters used in the EEX experiment

Beam line parameters	Value	Unit
Bending angle	20	deg
Dipole-to-Dipole distance	2.0	m
Dipole-to-TDC distance	0.5	m
$\eta$ (dispersion of dog-leg)	0.9	m
$\xi$ (momentum compaction of dog-leg)	0.3	m
$\kappa$ (TDC kick strength)	-1.1	m <sup>-1</sup>
Input beam parameters	Value	Unit
Beam energy	48	MeV
Charge before mask	5	nC
Charge after mask	~1	nC
Beam size at EY1	5	mm
Bunch length	1	mm

## DEMONSTRATION OF EEX BASED BUNCH SHAPING

All main content of this proceeding will be submitted to journal soon, so this proceeding only provides brief information about experiment and results.

We demonstrated three things from the experiment. The first demonstration was the zero-diagonal characteristic. To demonstrate this property, we used one of the quadrupole in front of EEX beam line. Normally quadrupole focus the beam in one of horizontal or vertical direction while defocus the other direction, and it does not introduce any change on the longitudinal. However, EEX beam line exchange the properties between horizontal and longitudinal. When the strength of quadrupole in front of EEX beam line is varied, it focus the beam vertically while increase the bunch length. In the opposite way, the bunch length decreases when the beam is defocused vertically.

After the zero-diagonal characteristic measurement, we demonstrated arbitrary current profile generation. Different mask were applied to the beam to generate special horizontal profiles: transversely separated two beam, triangle shape, rectangle shape, and trapezoid shape. After the EEX beam line, these special profiles successfully converted to longitudinal profiles, and the horizontal space loses its initial property and shows similar profiles at the end of EEX beam line.

The last demonstration was the aberration control method using incoming slope manipulation. The idea is cancel out the second order terms by manipulating incoming slopes. Transverse slopes were controlled by four quadrupoles and longitudinal chirp was controlled by linac phase. When the slope was close to the aberration minimizing condition, initial horizontal profile and final longitudinal current profile shows good agreements and they showed clear differences as slope moves away from the minimizing condition.

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