Triangular Current Profile for Future High-energy Accelerators

Beam-driven, collinear wakefield acceleration is one of the most promising methods proposed for the next generation of high-energy physics accelerators. This method has some similarities to a transformer where the wakefield plays the role of the voltage. A high-current drive beam experiences a low wakefield when it passes a media (e.g. plasma, dielectric structure, etc), and this is transformed into a high wakefield to accelerate a trailing low-current witness beam.

While high acceleration gradient (0.1-10 GeV/m) has been demonstrated for this method, its energy efficiency remains a critical issue. The efficiency depends on a parameter called the transformer ratio, which is the ratio of the wakefield behind the drive beam to the wakefield seen by the drive beam. This ratio does not exceed 2 when driven by a longitudinally symmetric drive beam. Triangular current profiles have long been considered to enhance the transformer ratio but, until recently, there has been no experimental demonstration of this enhancement.

Tailoring the longitudinal current profile is difficult since the beam is moving near the speed of light and is extremely short (ps/fs). A new method for controlling the current profile was recently suggested based on phase-space exchange, which exchanges the transverse and longitudinal properties. This provides a way to control the longitudinal properties by the manipulation of the transverse phase-space, which can be done simply with multi-pole magnets or collimating masks.

For the first time, the longitudinal current profile has been tailored using the exchange method. This was experimentally demonstrated at the Argonne Wakefield Accelerator facility (AWA) [1] using a phase-space exchange beamline (see Fig. 1) that consisted of four rectangular dipole magnets to apply the dispersion and a deflecting cavity for the time-dependent transverse kick to the beam.

The current profile was created by first applying a transverse mask to shape the horizontal profile of the beam (Fig. 1a). This horizontal shape was then converted into a longitudinal profile via the exchange process. Fig. 1b shows the 'x vs. z' image taken downstream of the beamline

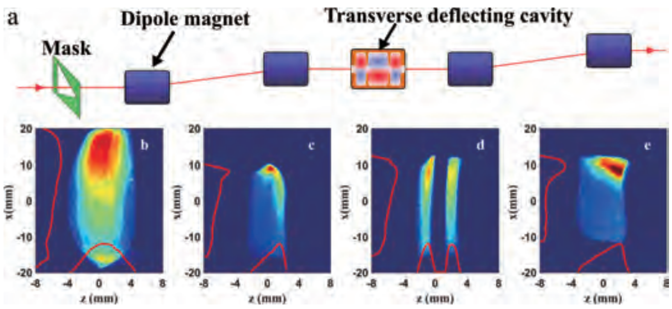

Fig. 1: (a) schematic of the double-dogleg emittance-exchange (EEX) beamline. A mask is placed in front of EEX beamline to shape the initial horizontal profile. Experimentally measured longitudinal current profiles (bottom row) were taken downstream of the EEX beamline: (b) without the mask and with the mask: (c) triangle profile generation, (d) two-beam generation, (e) trapezoid profile generation.

without the mask, where the beam has a symmetric current profile. A triangular current profile (Fig. 1c) was obtained by simply applying a triangular mask.

In principle, this method can generate arbitrary current profiles for other applications. During the experiment, a two-bunch train (Fig. 1d) and a trapezoid profile (Fig. 1e) were generated. Bunch trains can be applied to generate high-power THz radiation or X-rays. The trapezoidal profile can be used to suppress CSR which is one of the main concerns for state-of-art accelerators.

These experimental results confirm the versatility of the exchange based method. This newly demonstrated method may lead to advances in a wide range of future accelerator applications.

References

[1] G. Ha et al., Phys. Rev. Lett. 118, 104801 (2017).

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