Harmonic kicker test concept

(Living document)

M. Bruker*, G. T. Park, J. Guo, J. Musson, S. Zhang, T. Plawski, J. Grames

April 2022

We propose a modification of the existing UITF to perform a beam test of the harmonic kicker envisioned as a potential injection device for the RCS at the EIC. The kicker is an RF device that exerts a change in transverse angle as a certain function of RF phase, the idea being that this function can be designed to kick only every n^{th} bunch and leave the others unaffected. The objective of the test is to verify that the kick waveform and the resulting impact on the emittance agree with simulations.

*bruker@jlab.org

1 Introduction

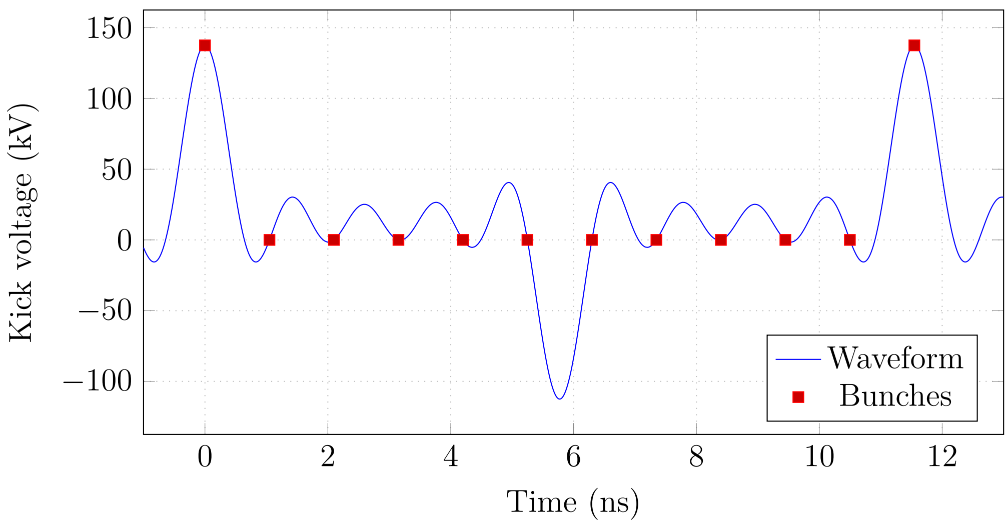

Figure 1: Kick action only on bunches at a bunch frequency equal to the fundamental of the kick waveform, $f_{\mathrm{HK}} = 86.6\,\mathrm{MHz}$; in this example, all 11 buckets are filled at a bunch frequency of $11 f_{\mathrm{HK}} = 952.6\,\mathrm{MHz}$.

The RF base frequency of the kicker is $f_{\mathrm{HK}} = 86.6\,\mathrm{MHz}$, which is not a subharmonic of the UITF booster frequency $f_0 = 1497\,\mathrm{MHz}$. While the kicker is designed to work with a bunch frequency of $11 f_{\mathrm{HK}}$ and kick every 11th bunch selectively (visualized in Fig. 1), our test will avoid the complication of diagnosing the resulting separated beams and instead put every bunch on the same phase of the kicker waveform, effectively turning the kicker into a DC steerer. The kick waveform can then be scanned by varying the global phase of the kicker waveform vs. that of the beam. The lowest bunch frequency to accomplish this while also being a subharmonic of f_0 is $f_0/121 = f_{\mathrm{HK}}/7 = 12.4\,\mathrm{MHz}$ [1].

[1]This kicker was originally designed for the electron cooler at JLEIC, which is why the frequencies are somewhat compatible to that of CEBAF.

The existing components of the UITF relevant to this study are shown in Fig. 2. Because 121 is odd, this assumption relies on the availability of a 1497 MHz buncher cavity (case B); the 750 MHz buncher currently installed will require halving the bunch frequency (case A).

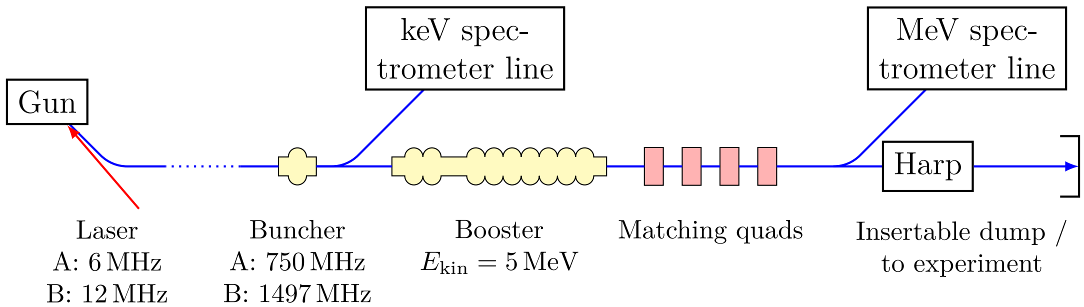

Figure 2: Existing UITF components relevant to this study.

2 Harmonic Kicker Diagnostic Line

We are envisioning a modification of the straight-ahead line with a new setup as shown in Fig. 3, called Harmonic Kicker Diagnostic Line (HKDL). Using the existing quads in the MeV section in conjunction with a downstream harp, the Twiss parameters after the booster can be obtained and matched to the experiment[2], while the longitudinal phase space can be measured using the existing MeV spectrometer line.

Two correctors will allow us to adjust both angle and displacement going into the harmonic kicker. Two BPMs downstream of the kicker will measure the exit angle. Another two correctors can then be used to correct for the change in exit angle so as to always be able to obtain the same orbit through the downstream quads, which, together with another harp, will be used for emittance measurements.

[2]This measurement was attempted in 2021 in preparation of this experiment, but the results remain inconclusive due to unresolved discrepancies.

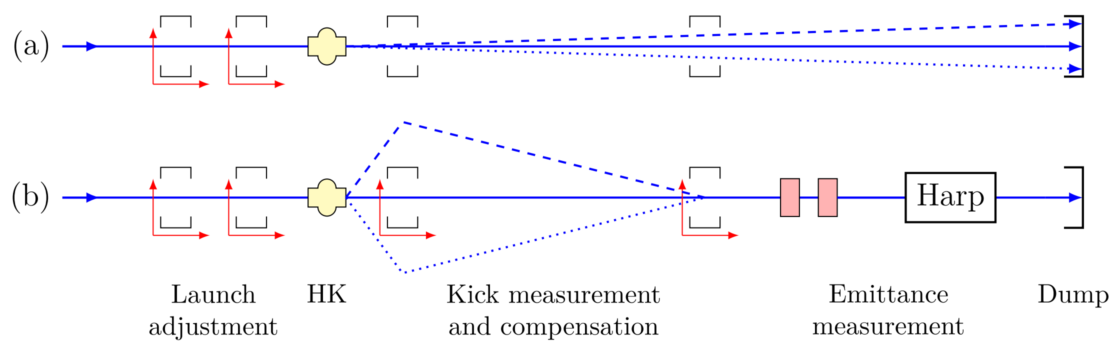

Figure 3: Conceptual sketch of a possible modification of the straight-ahead MeV line for the test of the harmonic kicker (HK). Figure (a) shows the essential parts of the setup for measuring only the deflection, while figure (b) includes a kick correction scheme to restore the orbit for consistent quad scans. The dashed and dotted lines are representations of the beam orbits with the kicker turned on and with its phase inverted, respectively; they are exaggerated for clarity in the bottom figure. All BPMs shown must be able to work at 6 or 12 MHz bunch frequency, depending on which one is chosen.

At 5 MeV, the kicker is expected to deliver about 4 mrad of maximum kick angle, while the geometric emittance is reasonably low. With a suitably short drift length of ~ 1 m, this gives a comfortable compromise without the need for a special vacuum chamber to accommodate the kicked beams; however, in principle, the beam energy can be set to other values should unforeseen circumstances require a different kick angle or a smaller emittance. The phase of the kicker can also be inverted to kick the beam in the opposite direction, effectively doubling the angular resolution of the measurement and exposing any potential geometric asymmetries. For the purposes of beam line and diagnostics commissioning, a corrector can conveniently be used in place of the kicker at first.

Turning this concept into a design will require the following input:

1. Desired / maximum permissible beam size and bunch length in order for the exit phase space to be comparable with the design; ideally a simulation study of the impact of these parameters.

2. Acquisition time / beam current to get the required signal-to-noise ratio from the available BPMs given the very low bunch frequency. Special detection circuitry may be needed for them to see any beam at all.

3. A way to make the low-frequency laser beam; see Section 3.

Table 1 lists the additional components needed with their tentative coordinates based on a preliminary beam optics study. While the Twiss parameters upstream of the matching quads are not precisely known and also energy-dependent, the matching quads are flexible enough to accommodate a range of values.

Figure 4 shows a prediction of the optical functions and beam trajectory for a realistic set of initial parameters. A simulated example of a quad scan to obtain the emittance in both planes is shown in Fig. 5.

Table 1: List of components to be added/changed, excluding vacuum plumbing, corresponding instrumentation, etc, with some relevant existing ones for reference. A corrector coil can temporarily be employed in place of the HK, allowing for commissioning of the beam line and especially the BPMs before the HK is ready for use. The names of the new components are chosen arbitrarily for the sake of naming them in simulation models. The coordinates of existing components are from the UED; the others are rough guesses and can be liberally adjusted to account for reality. Anything **bold** is new or changed.

Type	Name	s (m)
Quadrupole	MQJM504	15.8867
Viewer + IGP	ITVM504 (move)	**16.2**
Harp	was IHAM803 (move)	**16.4**
Beam line valve	was VBVM801 (move)	**16.6**
Corrector		**16.7**
Harmonic Kicker		**17.0**
Viewer + IGP		**17.2**
Beam line valve	VBVM601	17.5171
Corrector	MLHM601A	17.8602
BPM	IPMM601	18.0572
Dipole magnet	MDLM601	18.4718
Corrector	MBHM601B	18.7987
Viewer + IGP	ITVM601	19.1857
Beam line valve	VBVM602	19.3?
BPM	IPMM602	19.4107
Corrector	MBHM602A	19.6037
Quadrupole	Q721	**20.4**
Quadrupole	Q722	**21.4**
Harp	was IHAK501 (move)	**24.0**

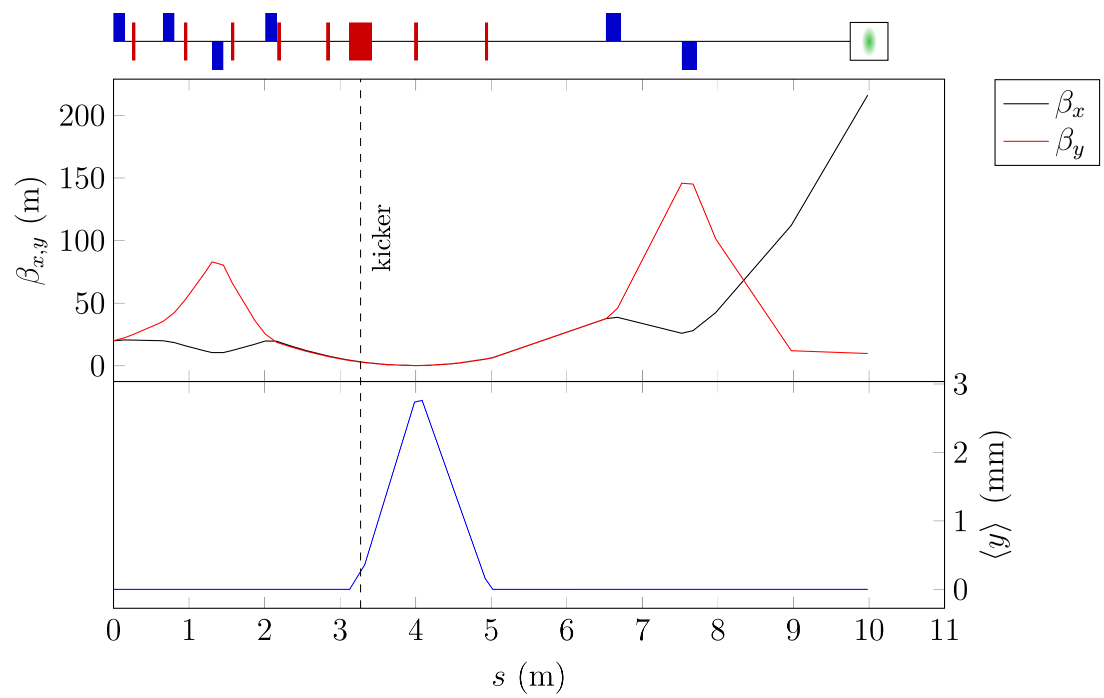

Figure 4: Elegant prediction of the HKDL optics. Blue boxes denote quadrupoles, while red boxes denote correctors (including the HK). The top plot shows the beta functions, while the beam centroid position is displayed in the bottom plot. This model assumes $\beta_x = \beta_y = 20\,\text{m}$ and $\alpha_x = \alpha_y = -5$ at the beginning of the matching quads, which are realistic values but depend on the booster settings and upstream optics. The quad strengths are chosen to produce a shallow beam waist at the first corrector after the kicker and a round beam at the first downstream quad while giving a reasonable scanning range for emittance measurements.

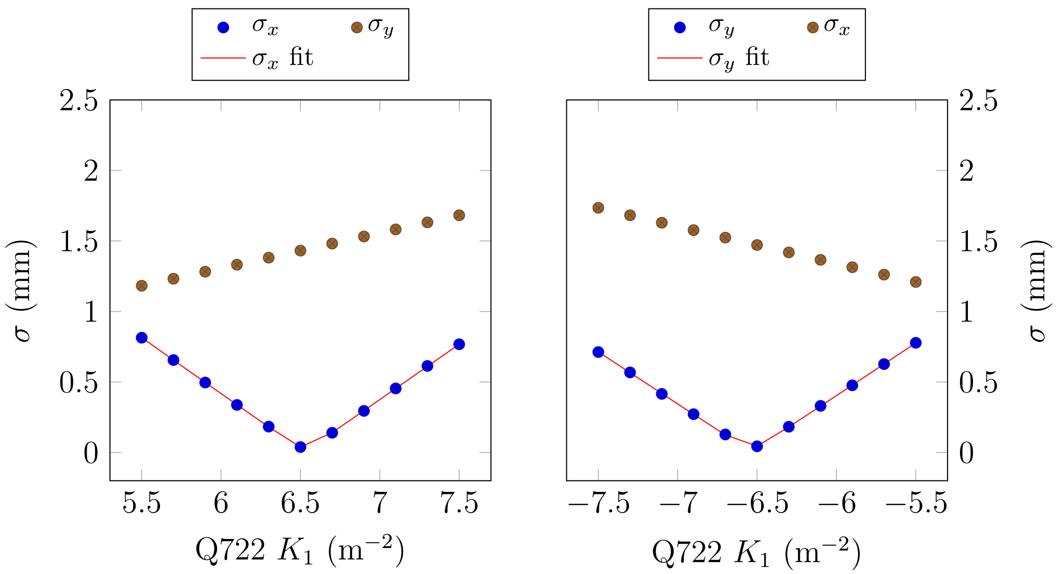

Figure 5: Simulated quad scans to determine the Twiss parameters downstream of the kicker assuming a geometric emittance of 30 nm in both axes. In this example, Q721 K_1 is set to $-5\,\mathrm{m}^{-2}$ and $5\,\mathrm{m}^{-2}$, respectively, to obtain a reasonable spot size in both axes at the harp. The fits are computed by Elegant; note that their visualization does not accurately show the shape of the curve at the minimum.

3 Laser setup

We expect the existing laser system to work at a repetition rate of 6 MHz or 12 MHz; synchronicity is achieved by generating a 6 MHz or 12 MHz trigger signal from a clock that is locked to the master oscillator. From this trigger signal, a pulse generator will produce a short-pulse drive signal for the laser. The pulse length and phase are expected to be independent of the repetition rate.

For beam setup purposes, it will be necessary to keep the usual beam modes available; the macropulse system will accomplish this without modification. The respective peak beam current ($\propto$ peak laser power) is determined by the radiological limit of the average current, which is expected to stay at 100 nA. The parameters are summarized in Table 2.

Table 2: Beam parameters for the design of the laser.

CW repetition rate	selectable
	749 MHz or 121$^{\text{st}}$ subharmonic thereof
Beam modes	viewer-limited, tune, CW
Maxiumum bunch charge	17 fC

4 Interference with other users

At this time, the time line of the kicker test cannot be predicted accurately, making it necessary to consider how the setup might need to coexist with existing and future experiments.

The straight beam line is currently terminated with a thin foil window, which allows the beam to exit the beam pipe and travel through air, irradiating samples mounted on a moveable stage behind the window. This irradiation setup demands a beam of large diameter (multiple cm) and an ideally homogeneous transverse profile, which is accomplished by a combination of a large overfocusing solenoid followed by a raster-magnet system to homogeneously paint the beam onto a large area. As the tentative HKDL design (Table 1) allows for these components to stay in place without changing the length of the beam line or any other components the irradiation setup depends on, no interference between the experiments is expected (other than venting). Neither the 800 line nor the diagnostic components being moved are important for the irradiation setup. In HKDL mode, the beam line will be terminated by an insertable dump in front of the window, which is already installed, even though the administrative limit for the average beam current supposedly makes it impossible to break the window by overexposure to the beam with a large safety margin.

Apart from the current irradiation setup, there is a possibility for a test of a polarimeter being added to the schedule. This modification would take place downstream of IYGM603 and therefore not interfere with those being proposed for the HKDL in a direct sense. However, it is expected that the polarimeter insertion will prevent beam delivery to the downstream harp while it is installed, so the beam schedules cannot overlap.