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STATUS UPDATE OF A HARMONIC KICKER DEVELOPMENT FOR JLEIC

Gunn Tae Park, Jiquan Guo, Shaoheng Wang, James Henry, Mattew Marchlik, Robert Rimmer, Frank Marhauser, and Haipeng Wang
Thomas Jefferson National Laboratory, Newport News, VA, USA

Abstract

An effort to develop the second prototype of the harmonic kicker for the Circulator Cooler Ring (CCR) of the Jefferson Lab Electron-Ion Collider (JLEIC) is under way. After beam dynamics studies and completion of a conceptual RF design of the kicker [1], further progress has been made toward the final mechanical design including the input power coupler (loop) design, tuner ports, multipacting studies. Furthermore, concerning the kicker's compatibility with beam dynamics, the impact of RF multipole components was investigated and a scheme was developed to cancel out detrimental beam effects.

INTRODUCTION

A harmonic kicker in the CCR of JLEIC is a crucial transporting element that injects/extracts electron bunch into/out of the ring within ultrafast time scale. Combined with beam dynamics study, the RF design of the second, high vacuum, high power prototype based on a quarter wave resonator (QWR) with base frequency of 86.6 MHz, was presented in [1] considering the latest beam parameters of the CCR [2] (For the first prototype development, see [3], [4]). Subsequently, nominal beam parameters have been updated to accommodate the higher envisioned proton beam energy (up to 200 GeV) and more realistic Courant-Snyder parameters and emittance for the CCR (See Table 1).

Table 1: The Beam Parameters of the CCR

Parameters	Unit	Value
Beam energy E_e	MeV	110
Kick angle θ	mrad	2.5
Turns N	-	11
Kick frequency f_k	MHz	86.6
Bunch frequency f_b	MHz	476.3
Bunch charge Q_b	nC	1.6
Bunch length l_b	cm	2
Energy spread δE	-	3×10^{-4}
Emittance ε^n	mm· mrad	36
α	-	0
β	m	120

Here the values of the Courant-Snyder parameters α, β are at the kickers.

In this paper, we report on the progress toward the fabrication of the high-power cavity taking into account these changes. The structure is now equipped with a power coupler, (realistic) tuners, and cooling channels. A single loop of the power coupler was designed to excite all the 5 harmonic modes with nearly critical coupling. A more detailed specification of the tuner plungers to prevent significant RF heat loss by introducing RF finger shortening the tuner port gaps was determined. The cooling scheme at full (~ 6.5 kW) RF power has been devised to keep wall temperature well below the limit set by the obtainable tuning range of the plungers. An assembly of the harmonic kicker with an input power coupler and a tuning station is shown in Fig. 1.

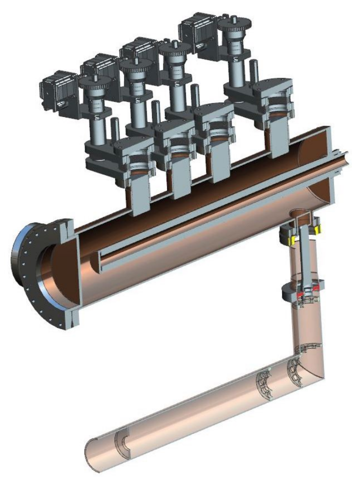

Figure 1: The assembly of the JLEIC ultra-fast harmonic kicker.

A numerical multipacting study showed that its bandwidth is well below that of operational kick voltage, suggesting that any multipacting can be overcome by various known techniques. An impedance analysis is almost complete suggesting that no HOM damper will be needed. The additional HOM power deposited in the structure is manageable within the thermal capability with the total power loss estimated to be below 7 kW. Beam dynamics relevant studies of the RF multipole effects of the kicker cavity shows that with the previous kicker configuration the multipole fields would result in an unstable circulation. However, a cancellation scheme without the need to modify the lattice structure of the CCR was devised and is reported here.

CAVITY DESIGN

Coupler Loop

A single power input coupler loop was designed to feed 5 harmonic modes into the kicker cavity with near critical coupling. The design was completed with extensive use of CST-MWS code [5] utilizing geometrical parameter scanning capability. The coupling is mostly inductive with the loop located near the top plate where the magnetic field is dominant. The loop is anchored on a rotatable flange so that coupling adjustment is possible before final installation. The detailed geometry of the loop is shown in Fig. 2a. In the simulation, we evaluated the coupling by using an artificial,

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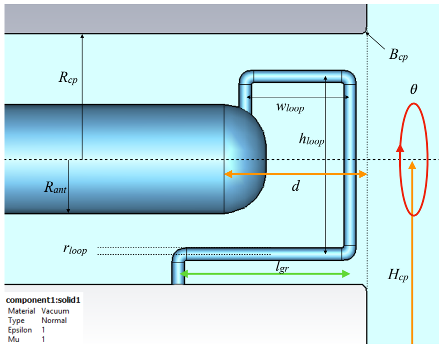
perfectly absorbing dissipative load at the coupler port for a more stable evaluation (See [6]). The angular profile of final coupling β's and the corresponding power are given in Fig. 2b and Table 2, respectively. The total power from the RF source adds up to 6.53 kW.



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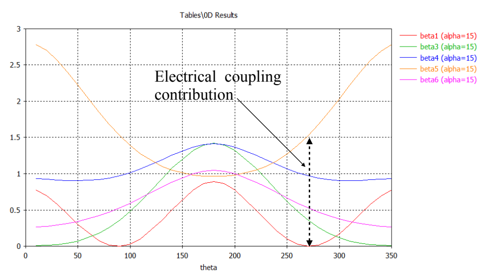


(b)

Figure 2: The design of the power coupler loop. (a) The optimized loop geometry. (b) The angular profile of coupling β's.

Table 2: The Figures of Merit for the Harmonic Kicker

Figures	Unit	1	2	3	4	5
f	MHz	86.6	259.8	433	606.2	779.4
β	-	0.74	1.21	1.23	1.20	1.26
P_g	kW	0.62	0.77	1.11	1.56	2.47
Q_0	10^4	0.57	0.95	1.31	1.55	1.70
Q_e	10^4	0.78	0.86	1.06	1.29	1.35
Δ_{3dB}	kHz	26	57	74	86	103

The RF Finger for the Tuner Plunger Ports

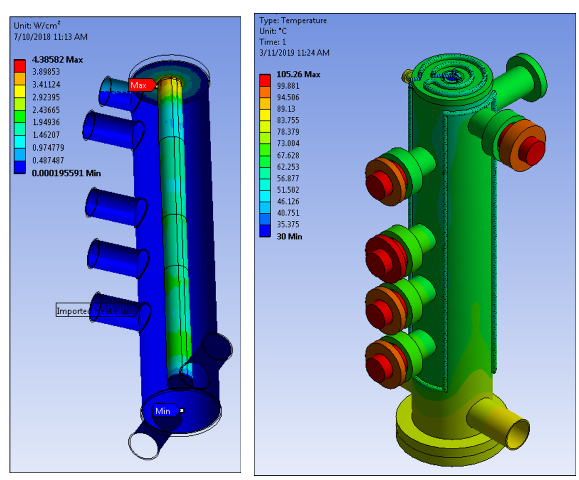
The five plunger/stub tuners are implemented to individually adjust the frequency shifts of the five harmonic modes. For practical reasons, a gap of 1 mm between the stubs and the tuner ports was allowed as clearance for the motion of the stubs considering some possible misalignment. Yet, the RF leakage through the gap can lead to significant RF power losses within the gap due to standing wave formation, in particular when stubs are moved into the cavity for tuning. Therefore, RF finger structures were added to shorten the gap length thus blocking the leakage [7] with the optimal port length up to the RF fingers determined numerically.

Multipacting Study

The potential multipacting in the kicker cavity was investigated by using CST-PS PIC solver. The regions where the multipacting is likely to take place are between the outer and center conductor, and near the top plate [8]. A two-point multipacting takes place between the conductors within the range of the kick voltage of 2.5 ~ 25 kV with a traveling period of ~ 6 ns (corresponding to half-period of fundamental mode). The increase in number alternates in this time period because electron kinetic energy and the corresponding SEY (secondary electron yield) are different at two conductor walls.

Mechanical Design

A thermo-mechanical analysis using ANSYS [9] at the nominal average power of ~ 6.5 kW was done with a simplified geometry of the kicker cavity (4 mm wall thickness, without tapering on the inner conductor). The simulation includes a generic motion of the stubs for frequency tuning, which increases the power no more than 100 W's. With water cooling channels implemented within the inner conductor, on the end-plate, and around the outer conductor, the temperature profile at full power is shown in Fig. 3. The hottest region, due to the strong magnetic field, is the end-plate with the temperature reaching ~ 77°C for an inlet water temperature of 40°C. The resulting temperature gradient leads to a frequency shift in the range of $\delta f/f \sim 6 \times 10^{-4}$ (for all the modes), which is well within tuning range of 7.5×10^{-4}.



(a) (b)

Figure 3: Thermal analysis of the QWR. (a) The power distribution of the QWR. (b) The temperature distribution of the QWR.

For structural stability, the end-plate was reinforced by using a thicker wall, which reduced the amplitude of the modal vibration (the pendulum mode) found at ~ 39 Hz.

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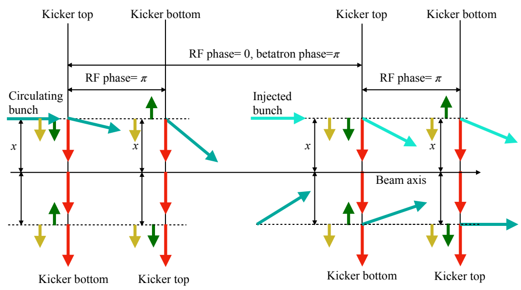
THE EFFECTS OF MULTIPOLES ON BEAM DYNAMICS

Due to vertically asymmetric geometry, the QWR has non-zero multipole fields, dipole fields in particular [10]. Beam dynamics simulation using ELEGANT showed this makes the electron beam re-circulation through the CCR unstable and needs to be suppressed.



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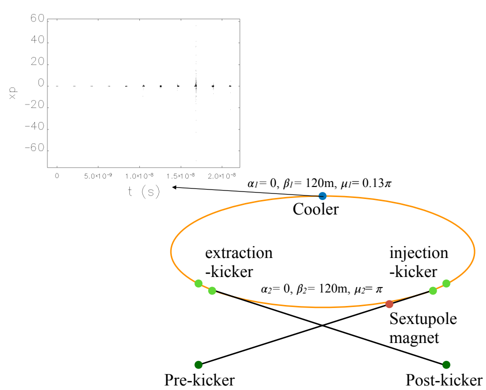
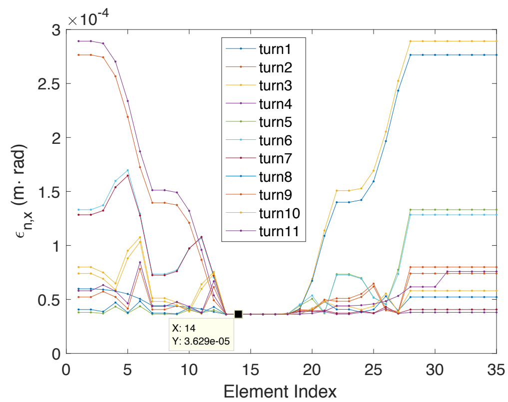


(b)

Figure 4: The schematics of the kicker system in the CCR. (a) The schematic of the kicker system. The kick of kicker is a vector sum of red(dipole), green(quadrupole), and yellow(sextupole) arrows. The circulating bunch is represented by dark blue and multipole effects is cancelled. (b) The schematic view of the CCR with kicker system and a sextupole magnet. Shown is the temporal profile of angular distribution of the bunches without any cancellation scheme.

Cancellation Scheme

A baseline configuration for the kicker system-before a multipole field study was conducted- implied that the IK (injection kicker) and the EK (extraction kicker), oriented in the same direction, are separated by betatron phase of π with RF phase being the same. In order to cancel multipole effects taken place between the EK and IK, we change the configuration so that the IK and EK exhibit RF phase difference of π with the EK oriented upside down. With proton beam energy for JLEIC now upgraded to 200 GeV, which translates to 110 MeV beam energy for the CCR, a pair of kickers would be used for each of IK and EK. The schematic for kick system is shown in Fig. 4a. Taking into account betatron phase advance of π, one can see that the multipole effects at EK are completely cancelled by the multipoles of the IK for each turn, except for the 1st turn, where the multipole effects imprinted on the beam by the IK is not matched and survives the total of 11 turns. These multipole effects will be removed by sextupole DC magnet positioned in the injection transport system (see Fig. 4b) without having to modify the lattice of the CCR.



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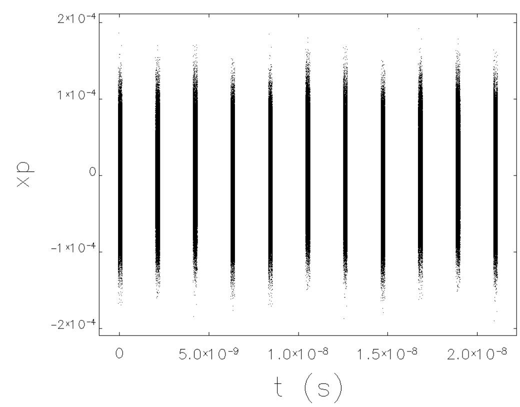

(b)

Figure 5: The beam dynamics of the CCR with cancellation scheme. (a) Emittance change with the cancellation scheme installed. The element index x refers to the lattice element used in ELEGANT. $x = 1 \sim 13$ is the IK, $x = 14$ is the cooler position, and $x = 15 \sim 27$ is the EK. (b) Angular divergence of bunches throughout 11 turns at the cooler.

Simulation Results

In Fig. 5, simulation results for the proposed cancellation scheme are shown. Due to the cancellation scheme, the angular profile (distribution of slope xp) of each bunch throughout 11 turns are roughly below 0.1 mrad, which is about the same as that of initial beam before injection into the CCR (transverse beam size and phase space distribution also did not change). Slight fluctuations in xp are believed to be caused by higher order multipoles, octopoles and decapoles by the IK in the first turn. The normalized emittance (in kick-direction) at the cooler location also did not change

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significantly from its initial value (36 mm-mrad to 36.3 mm-mrad).

CONCLUSION

The second prototype of the harmonic kicker for the CCR of JLEIC is near the end of design phase. With the power coupler, tuner, and cooling channels installed for the operation at the RF power of 6.5 kW, the prototype fabrication will start in near future.

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