A HARMONIC KICKER SCHEME FOR THE CIRCULATOR COOLER RING IN THE MEDIUM ENERGY ELECTRON ION COLLIDER*

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Abstract

The current electron cooler design for the proposed Medium energy Electron-Ion collider (MEIC) at Jefferson Lab utilizes a circulator ring to reuse the cooling electron bunch up to 100 times to cool the ion beam. This cooler requires a fast kicker system for injecting and extracting individual bunches in the circulator ring. Such a kicker must work at a high repetition rate, between 7.5 and 75 MHz depending on the number of turns in the circulator ring. It also must have a very short rise and fall time (of order of 1 ns) such that it will kick an individual bunch without disturbing the others in the ring. Both requirements are orders of magnitude beyond the present state-of-the-art as well as the goals of other on-going kicker R&D programs such as that for the ILC damping rings. In this paper we report a method of creating this fast, high repetition rate kicker by combining RF waveforms at multiple frequencies to create a kicker waveform that will, for example, kick every eleventh bunch while leaving the other ten unperturbed. This work will include both the method itself, its limitations, and methods of implementation.

INTRODUCTION

The current plan for the Medium energy Electron Ion Collider (MEIC) uses electron cooling to attain its design luminosity [1]. This cooling is accomplished at energies far higher than current electron cooler technology, which necessitates a long cooling section, as well as a high electron current and bunch charge. The current scheme involves a 54 MeV beam with 2 nC bunch charges, at a repetition rate of 750 MHz. Not only is this beyond the state of the art for electron sources, it is also above current limits for beam dump power.

In order to fix this problem the design calls for both energy recovery of the cooling bunches, and their reuse 10-100 times. A basic outline of the planned cooling complex [2] is shown in Fig. 1.

This design would reuse the cooling beam in the circulator ring for 10 to 100 turns, with the bunches stacked to coincide with the ion collider repetition rate of 750 MHz. Several bunch replacement methods have been investigated, the methods envisioned would replace individual bunches in a train. Since the spacing between bunches is very small, a kicker that can hit an individual bunch without affecting the others becomes necessary. Kickers with rise times on the order of a nanosecond have

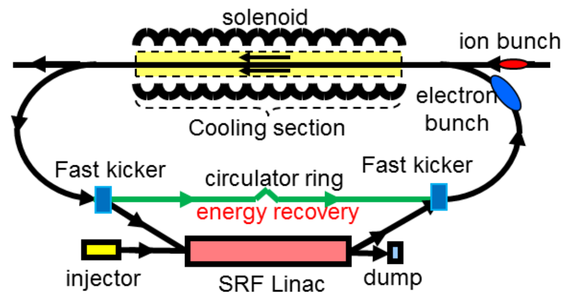

Figure 1: An outline of the proposed cooling complex.

been investigated for use in the damping rings of the ILC, however the power supplies for those kickers are used in a so called "Burst Mode" where they have their high repetition rate but only for a period of time long enough to fill or empty the damping ring [3]. For the purposes of the cooling ring in MEIC we require a kicker than can operate for the entire period of time that the machine is colliding.

We propose a method that would combine a series of waveforms onto a stripline kicker such that they will act like an RF separator but only kick the bunches periodically. In this work we will first outline the scheme of this harmonic kicker and how it works in practice, followed by an analysis of the requirements for the power source, and finally a proposal for a test program.

HARMONIC KICKER

The harmonic kicker works by combining a series of frequencies into one stripline such that they create a waveform similar to the one shown in Fig. 2.

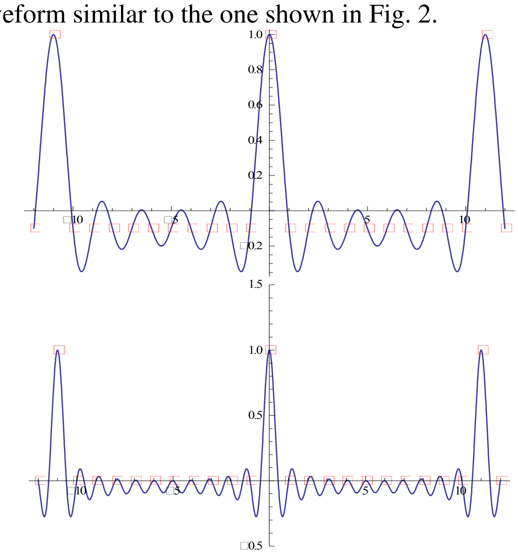

Figure 2: This shows the waveform that results in a kick to every eleventh bunch with the other bunches receiving a smaller opposite kick.

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Some work has been done on combining high order modes for longitudinal RF acceleration [4]. These operate via a properly shaped and prepared cavity. While one of these designs may be used in a tilted manner for the MEIC cooler [5], more work needs to be done to ensure its suitability.

The method does not use a Fourier decomposition, instead it combines un-normalized frequencies that form the function F,

$$F(n,n_1,\omega,t)=\frac{1}{n_1}\sum_{k=1}^{n_1}Cos\left(\frac{k\omega t}{n}\right). \quad 1)$$

Where n_1 frequencies are used to kick every n^{th} bunch from a beam with frequency ω. As is seen in the top image in Fig. 2, the "unkicked" bunches all receive a much smaller kick in an opposite direction from the main beam. Using the waveform in the lower image the unkicked beam will receive no kick, however it requires more subfrequencies.

The pattern of having a kick every n^{th} bunch, but none on the others works for odd n, with the lowest number of frequencies to achieve this adheres to the rule,

$$n_1=\frac{n-1}{2}. \quad 2)$$

The top example in Fig. 2. is achieved with 5 harmonics, while the lower example is achieved with 11. For numbers of bunches being kicked that are small, δ (n)<13, this is possible. As can be seen in Fig. 3, for larger numbers this method can become problematic. For instance, if we wanted to kick every 101^{st} bunch, that would require 50 frequencies. If the unkicked tolerances are relaxed there will be a dropoff in the number of required frequencies to kick a beam, however as can be seen in Fig. 3, this dropoff doesn't take effect until n>30, and it requires a high acceptance on the part of the cooler.

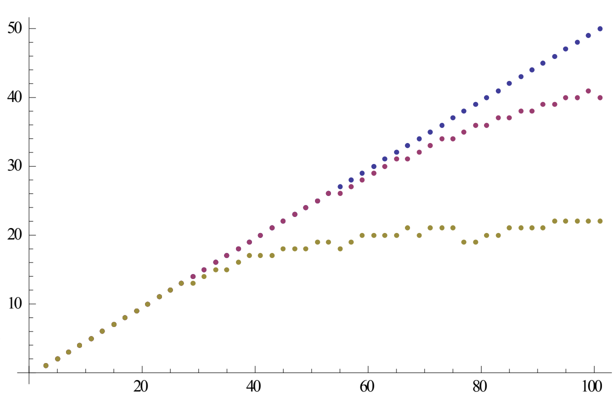

Figure 3: The blue line shows the order required to have equal unkicked values for a given n. The purple shows the number of frequencies required if the average unkicked kick is no more than 2.5% of the kick value, while the yellow represents the number of frequencies with an average unkicked value of 5%.

KICKER IN PRACTICE

The kicking scheme that we envision for this type of kicker would make use of these periodic kicks, with adjustments made to the size of the recirculating ring that would permit the kicker to essentially "walk" the kicked bunches around the circulator ring. An example is shown in Fig 4. In this example every third bunch is kicked, and the ring is sized such that there are 5 bunches in it at any given time. As is seen in the figure as the beam makes its kick every 3 turns it walks along the beam, allowing the separation scheme to operate in a continuous wave mode.

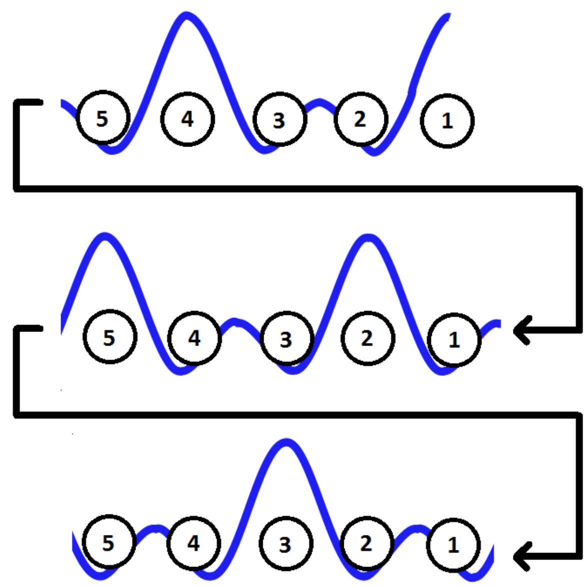

Figure 4: An illustration of the kicking scheme which will 'walk' the kicked bunch along the beam.

GENERATING THE WAVEFORM

In order for this kicker to work we must combine harmonically related frequencies of equal amplitude in the same structure. The simplest method of creating this waveform, and the one we intend to test, would be to combine the frequencies at a low level and then use a broad spectrum amplifier to bring them up to the required power. However since the gain is only required at a few fixed frequencies this is not the most efficient way to proceed, and could allow unreasonable amounts of background noise to affect the kicker and the beam. Another method would be to add together the outputs of several narrow band amplifiers at high power. However this would also be inefficient since the power required in the final waveform is smaller than the power of the individual frequencies due to the interference of the waves. One possible solution is to create an amplifier that has a gain at each of the desired frequencies, though this hasn't been done it is conceptually possible.

One method to efficiently pair the waveform to a stripline is to employ a resonant ring that could reroute the RF power that comes out of the stripline, with power losses topped off with a directional coupler. The length of the resonant ring would have to be matched with the repetition rate of the beam, and its inner diameter matched to the frequencies of the harmonics.

TEST FACILITY

We currently are planning on testing the broad spectrum amplifier scheme as part of our research and development plans. We intend to drive a surplus stripline kicker using a fabricated power supply. This should show that a kicker can be driven that will kick every eleventh bunch of a 750 MHz beam.

The envisioned test will involve taking a source at the repetition rate of the circulator ring, and running it through a frequency divider. These subfrequencies will then be passed through notch filters before having their signals recombined. The resulting waveform will be sent into a wide band amplifier before being sent into a stripline kicker [6]. A diagram of this proposed setup is shown in Fig 5.

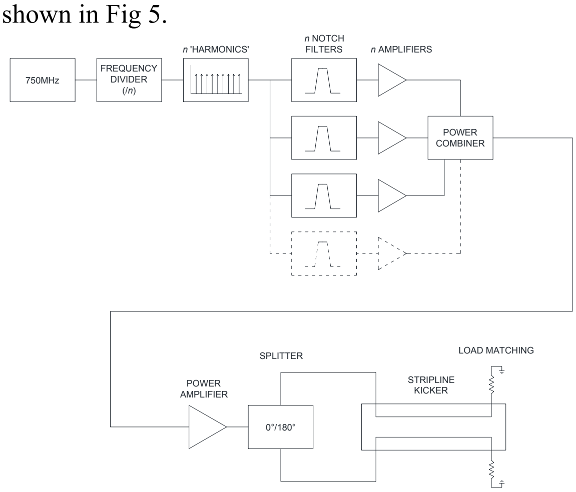

Figure 5: This is a block diagram of the proposed experimental setup.

We also plan to test this concept in our proposed test facility. We currently intend to use surplus equipment to add a set of additional bends to the JLab FEL facility between the infra-red and ultraviolet lines to form a small circulator ring. Two possible designs for this test facility are shown in Fig 6.

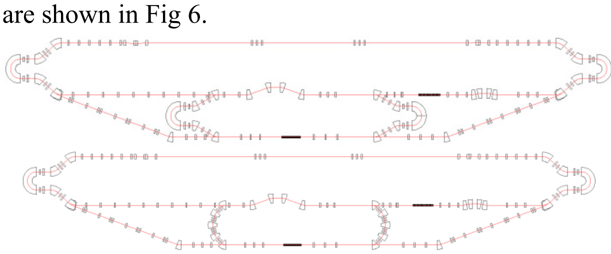

Figure 6: Two possible methods of creating the test facility in the FEL using surplus magnets from the FEL test facility.

Simulations of the dynamics of the cooling beam in the circulator ring are ongoing, and will dictate the final design of the test facility. The facility is meant to test both the injection/extraction kicker methods, as well as the ability to store the beam under the influence of collective effects such as Coherent Synchrotron Radiation (CSR) and space charge.

CONCLUSIONS

The electron cooling system that is required for the MEIC project needs to re-use each electron bunch in the cooling section at least 10 times. In order to maintain a high duty factor, a fast kicker with a short rise and fall time needs to be developed to continuously replace the beam. One method of achieving this is to use a series of overlapping harmonics to create a waveform that will kick every n^{th} bunch in a train, if n is not a multiple of the number of bunches in the ring, then each bunch will be replaced after n turns. We intend to test this scheme using a stripline kicker, and eventually to use it as part of an ERL circulator electron cooler test facility built around the JLab FEL.

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