

KINK INSTABILITY SUPPRESSION WITH STOCHASTIC COOLING PICKUP AND KICKER*

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Abstract

The kink instability is one of the major beam dynamics issues of the linac-ring based electron ion collider. This head-tail type instability arises from the oscillation of the electron beam inside the opposing ion beam. It must be suppressed to achieve the desired luminosity. There are various ways to suppress the instability, such as tuning the chromaticity in the ion ring or by a dedicated feedback system of the electron beam position at IP, etc. However, each method has its own limitation. In this paper, we will discuss an alternative opportunity of suppressing the kink instability of the proposed eRHIC at BNL using the existing pickup-kicker system of the stochastic cooling system in RHIC.

INTRODUCTION

The main advantage of an energy recovery linac (ERL) based electron ion collider (EIC) over a ring-ring type counterpart is the higher achievable luminosity. In ERL-based version, one electron bunch collides with the opposing ion beam only once so that the beam-beam parameter can largely exceed the usual limitation in an electron collider ring, while the beam-beam parameter for the ion beam remains small. In this, so called, linac-ring collision scheme the resulting luminosity may be enhanced by one order of magnitude.

The beam dynamics related challenges also arise as the luminosity boost in the ERL based EIC due to the significant beam-beam effect on the electron beam. The effects on the electron beam are discussed in [1]. The ion beam may develop a head-tail type instability, referred as 'kink instability', through the interaction with the electron beam.

A special active feedback system [2] was carried out to suppress the kink instability without any modification to the ion ring (i.e. existing RHIC ring for eRHIC project). However, limitation was found in that method, which requires the disruption parameter for the electron beam to be less than 20. For suppressing the kink instability with larger disruption parameter, in this paper, we are exploring the method with pickups and kickers, similar to transverse stochastic cooling layout. The inner structure of the beam is detected by the pickup and passed to the kicker, while the high frequency kick corrects the beam accordingly.

THE KINK INSTABILITY ANALYSIS

Before applying the feedback system, we will first demonstrate the effect of the kink instability and analyze

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Table 1: Kink Instability Main Parameters of eRHIC

Parameters	Values
Disruption parameter for e-beam	up to 150
Beam-beam parameter for ion beam	0.015
rms ion bunch length (m)	0.083
Chromaticity of ion ring, x/y	2/2
Synchrotron tune of the ion ring	4.6×10^{-4}

the frequency contents of the modes. Simplest 2-particle linear model predicts the threshold of this instability as

$$d_e \xi_i < \frac{4\nu_s}{\pi} \quad (1)$$

where ν_s is the synchrotron tune, ξ_i is the beam-beam parameter of the ion beam, d_e is the disruption parameter which is defined as $d_e = l_i/f_e$ with given ion rms bunch length l_e and beam-beam focal length f_e . This only holds when d_e is small (less than 5). For large d_e case, the threshold show complicate patterns[2] with multi-particle linear models.

We use simulation code, EPIC[3], to predict the behavior of instability. The key parameters are listed in table 1. In simulations, we fix the ion beam-beam parameter and vary the disruption parameter by modifying the energy of the electron beam.

Figure 1 (top) shows that the emittance of the ion beam grow because of the interaction. This confirms that the parameters is beyond the kink instability for all disruption parameter cases. Illustrated earlier work[1], the electron beam oscillates inside the opposing ion/proton beam; if the ion beam has Gaussian longitudinal distribution, the oscillation time is given by $\sqrt{a_e}/4$. This generate a strong and high frequency wake field around the interaction region for the ion beam, when disruption parameter is high.

We record the turn by turn data of the centroid of each ion slices, then use Fast Fourier Transform to analyze the frequency components of the modes from in the kink instability, as shown in bottom one of figure 1. There are rich information in the frequency spectrum. Each peak corresponds to a mode excited by the effective wake field that the proton beam encounters. The feedback system we study below has a specific bandwidth and correct the beam in this bandwidth coherently to suppress the instability. It is worthwhile to note that, the frequency of each peak (mode) is only the function of the bunch length and longitudinal distribution of the ion beam. In this study, we are varying the disruption parameter by the electron beam energy (hence varying f_e), therefore the position of the peaks for

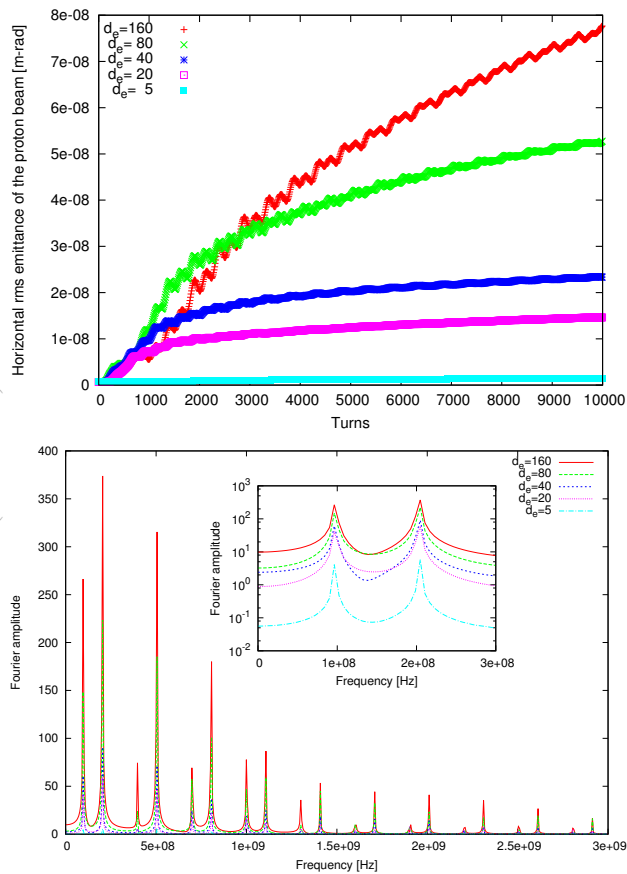


Figure 1: Top: The proton beam emittance growth due to kink instability at different disruption parameter. Bottom: The Fourier components of the turn by turn proton slice centroid data. The proton beam is cut to 100 longitudinal slices.

different d_e resides at same frequency with their own amplitudes.

PICKUP-KICKER FEEDBACK SYSTEM

This feedback system consists a high bandwidth pickup (BPMs) that samples the offset within one ion bunch, and a set of wide bandwidth kicker (usually RF cavities or strip lines) that correct the offsets accordingly. It is expected that the instability will be suppress if the instability mode frequencies fall in the bandwidth of the feedback system.

To simulate the effect of this system, we model this system with a band pass filter in the beam-beam interaction code, EPIC[3]. For a sharp edges at a low and high frequency limit f_L and f_H . The corresponding wake field of this system reads[4]:

$$W(\tau) = R \int_{f_L}^{f_H} \cos(2\pi f\tau) df \quad (2)$$

where R is related to gain of the amplifier between the pickup and the kicker.

To suppress the kink instability for specific disruption

Table 2: Kink instability suppression in certain frequency ranges

Index	f_L (MHz)	f_H (MHz)	d_e range suppressed
1	50	300	5-25
2	300	600	5-30
3	600	900	5-50
4	900	1200	5, 25-80
5	1200	1500	50-90
6	1500	1800	80-90
7	1800	2100	None
8	2100	2400	None

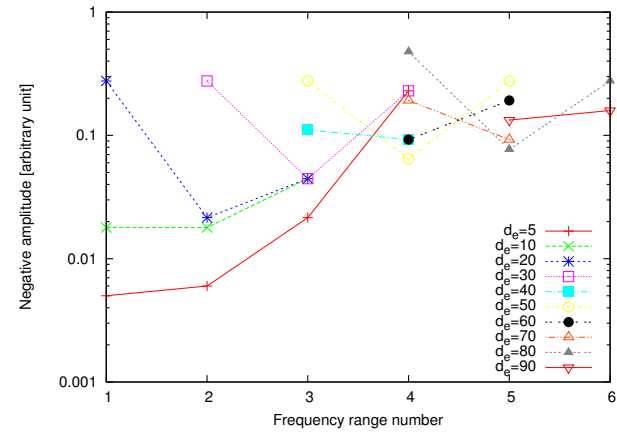


Figure 2: The minimum amplitude of the feedback system to suppress the kink instability for different frequency range index and disruption parameter.

parameter d_e , the frequency range and the gain has to be determined from simulation. However, it is very consuming to find the exact f_H and f_L for each d_e that in the interest range as shown in table 1. Instead we divide the frequency range to subranges with 300 MHz bandwidth, and find the disruption parameter that can be suppressed within, as shown in table2. In the first subrange, we avoid DC components and select the lower boundary as 50 MHz, which is less than the frequency of the first peak.

From table 2, we observe general trend that higher d_e requires higher frequency with same bandwidth. If disruption parameter is higher than 90, 300 MHz bandwidth is too small, even f_H and f_L continue grows together. This indicates the requirement for larger bandwidth. For one specific disruption parameter, there is more than one possible range that can suppress the instability due to the coupling between modes. For instance, the case with $d_e = 30$ can be suppress by frequency range 2 to 4 in table 2. However, in different ranges, the required minimum amplitude of the feedback system differs, since the coupling strength varies. Figure 2 shows relative minimum amplitude to suppress the instability for different disruption parameter at certain frequency range number as shown in table 2. Each disruption parameter case has its best suitable frequency range,

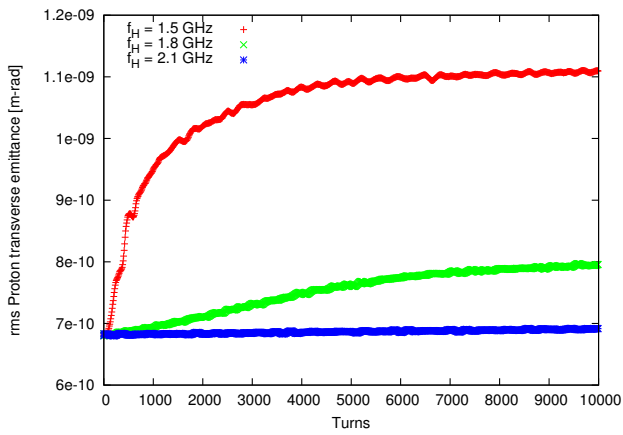


Figure 3: Comparison of kink instability damping with different high frequency limit f_H when disruption parameter $d_e = 150$. The gain of the feedback is selected to minimize the emittance growth ion beam.

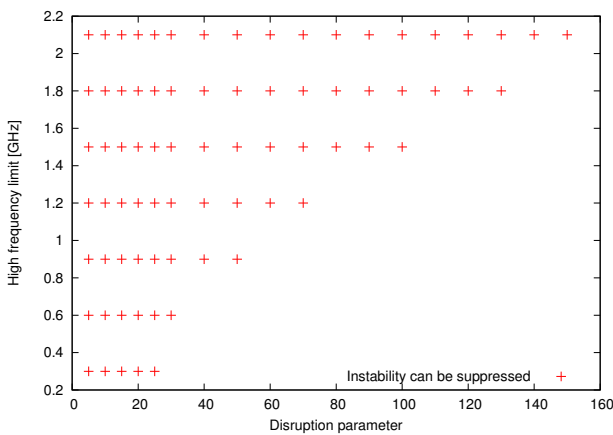


Figure 4: The relation between the required high frequency limit f_H and the electron disruption parameter d_e . Each point denotes that the instability can be suppressed in the corresponding parameter (f_H and d_e) with proper amplitude. For all calculations, the low frequency limit is fixed to 50 MHz.

in which requires minimum amplitude of the feedback system. The value of the amplitude is a function of the optics functions of the pickup and kicker, and the phase advance between them. In this paper, we only intend to compare their relative values.

Since eRHIC requires the disruption from 5 up to 150, we need much larger bandwidth than 300 MHz to cover the whole range from above analysis. To simplify the problem, we fix the low frequency limit f_L to stay at 50 MHz and scan the high limit f_H to suppress the instability for the interested range of disruption parameter listed in table 1.

Figure 3 shows that the required f_H is at least 2.1 GHz to suppress the kink instability when d_e is 150. If we vary the high frequency limit values according to the third column of table 2, as expected, we conclude that the required

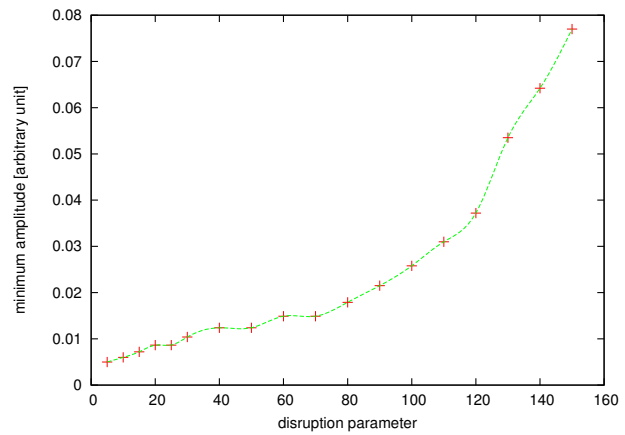


Figure 5: The minimum amplitude of the feedback system with ($f_H = 2.1$ GHz and $f_L = 50$ MHz) to suppress the kink instability for different disruption parameters.

f_H is a monotonically increasing function of d_e as shown in figure 4. The minimum amplitude can be found for each disruption parameter case. It also monotonically increases as higher d_e cases are considered. It is worthwhile to note that there is also a maximum amplitude for each case. The system gets 'over kicked' and becomes unstable again, if the amplitude exceeds the limit. Simulation gives the estimate of this limit as 0.16 for this frequency range. This limit is not sensitive to the different disruption parameters.

CONCLUSION

We demonstrated that the kink instability will be suppressed by a pickup and kicker system with whole electron beam disruption parameter range (5-150), if proper frequency bandwidth is selected. Through parameter scanning in simulation, we determined the higher limit of frequency window. Other detail studies, including the lower limit of the range and the power requirement of the feedback system, are undergoing.

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