Recycler Tune Shifts Due To Main Injector Ramps

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Abstract

The purpose of this project is to, at least preliminarily, determine the effect of the ramp of Fermilab's Main Injector (MI) on the tune of the antiproton storage ring, the Recycler. As the Main Injector raises the energy of its beam (ramps) every few seconds, the magnets that keep the beam at a nearly constant radius must compensate for the extra acceleration the particles experience. In doing so, they cause the magnetic field in not only the Main Injector, but also the Recycler to change. Although the effect is small in the Recycler compared with that of the Main Injector, it does produce a small but measureable tune-shift in the Recycler's beam. The effects are seen in both the horizontal and vertical directions, but naturally to varying degrees. This study begins to explore these effects and to quantify the relationship enumerated above.

1 Introduction

It is known at Fermilab that the Recycler tunes are affected by the Main Injector's ramp, and there have even been preliminary studies on these effects which have shown them to be relevant. However, the automated and continuous collection of a large amount of data on this subject is a project that has not been undertaken to date.

Currently, the operation of the Recycler is based on a tune measurement that is averaged over the course of several ramps. This measurement, while fairly accurate, does give something of a false impression that the Recycler's tune is stable over long periods of time. In fact, as is known, the tune shifts noticeably during the MI ramp. This study is (hopefully) the beginning of an automated system that will collect more accurate data on the Recycler's tunes over the Main Injector's ramp.

2 Experimental Setup

2.1 Preliminary Data

For the first iteration of data collection we simply wanted to verify the correlation between the MI ramp and our Recycler tunes. To do so, we used a gating system for our vector signal analyzer (VSA) such that it would only take data at certain time ranges in the ramp. We then determined the tune by reading the vector signal analyzer by hand. Given that the VSA only averaged data for a slim slice of the ramp, we got a fairly nice idea of how the tune in the Recycler changed over the time of each 23 (or, in this case, 29) event, Figure 1.

2.2 Open Access Client

After having seen these preliminary data, we automated the control of the VSA by way of an Open Access Client (OAC). An OAC is a java class that is called upon by Data Acquisition Engines (DAEs) on Fermilab's Accelerator Controls Network and carries out numerous repetitive or time-dependent tasks. The new OAC, RCYSCH (after Recycler-Schottky), automates the process of collecting Recycler tune data. It collects two types of data, one being the Tune vs Time data like the preliminary set. The other shows the effect of the VSA's arm gate width on the measured tune at a given time of the ramp (i.e. how different arm gate widths change the measured tune .5 seconds after a 23 event). RCYSCH then dumps the data it collects to one of Fermilab's data servers to be downloaded and analyzed.

3 Data

The first measurement that we took was, as explained above, the dependence of our tune reading on the width of our VSA's arm gate. We did this in the hopes of finding an appropriate gate width for the arm signal such that we could gather accurate data without each measurement requiring hours of averaging. Implementing a wide arm signal will

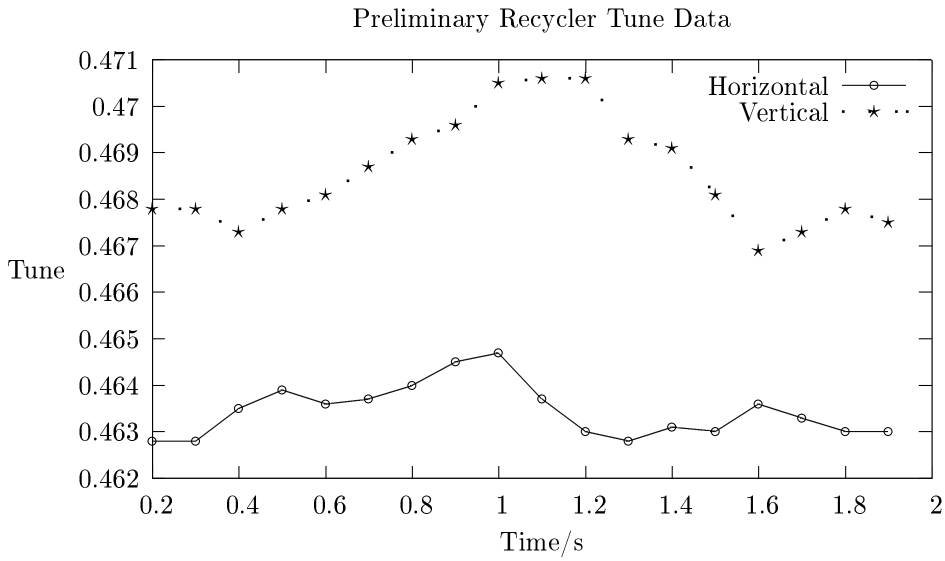

Figure 1: Preliminary RR Tune vs MI Ramp Time

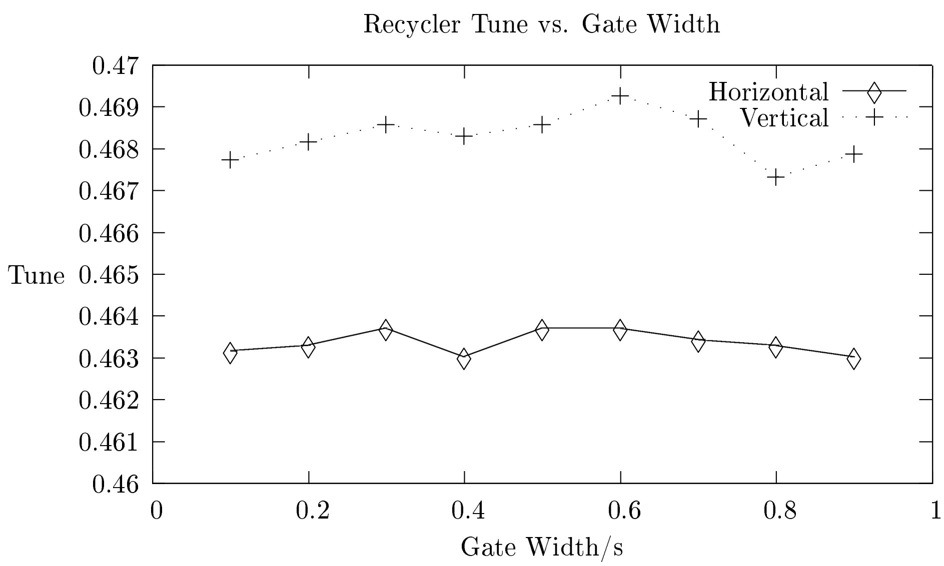

Figure 2: Rising, 1.1 seconds afte rthe $23 event

let the VSA spend more time averaging and less time waiting for the signal than a narrow one, but a wide signal in principle should also be less accurate because the averages are taken over much more of the ramp–exactly what we are trying to avoid.

We took three sets of data, Figures 2,3 and 4, for this measurement, one for the Main Injector ramp's rising edge, falling edge, and at the peak of the protons' momentum. Each trace was averaged 20 times before its peak was found and plotted against the gate width time.

4 Gate Time

Our second measurement was taken with a gate width of .075 s and spanned the whole MI ramp. Each trace on the VSA was averaged 50 times before its peak was found and plotted against its time after the $23 event. With this data, Figures 5 and 6, we hoped to see the actual correlation between the Recycler's tunes and the ramp by comparing the tune and MI current bus time data.

Also important to this study are the bus currents in the Main Injector's dipole and quadrupole magnets, since they are what actually cause the magnetic field in the Recycler's ring, which in turn changes the tunes. We are most interested in the *difference* between the two buses, since they run in opposite directions and have cancelling magnetic fields. We obtained this data from Fermilab's servers, Figure 7.

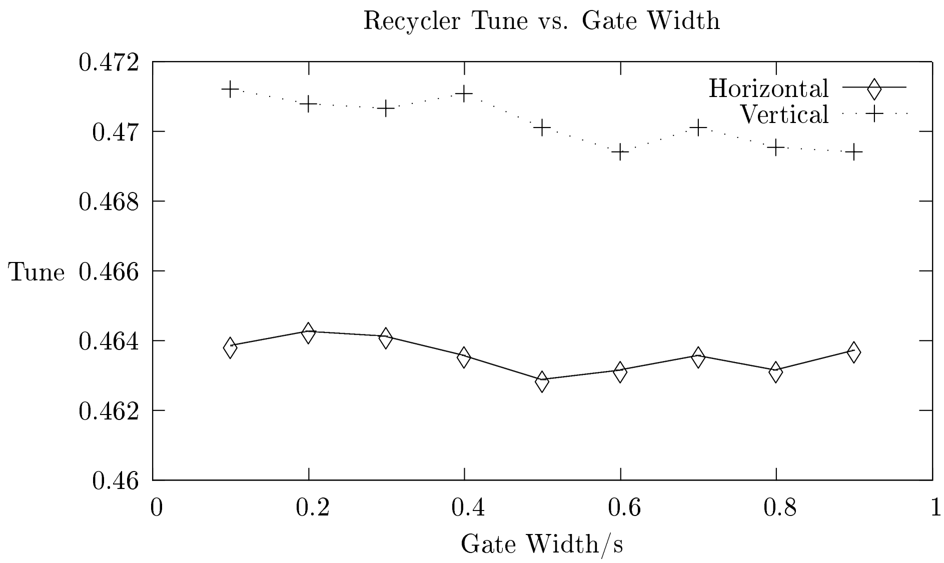

Figure 3: Top, 1.5 seconds after the $23 event

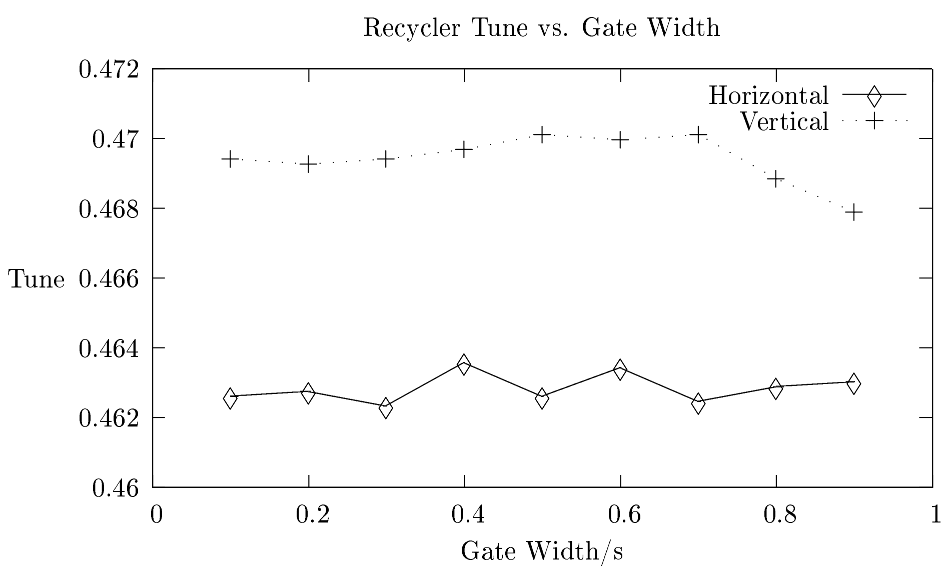

Figure 4: Falling, 1.75 seconds after the $23 event.

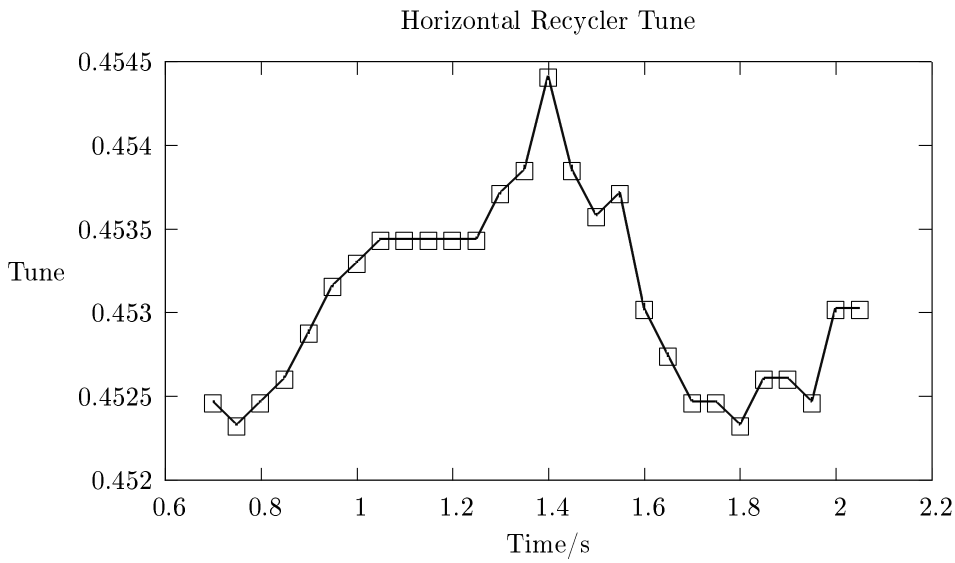

Figure 5: Horizontal Tune vs MI Ramp Time

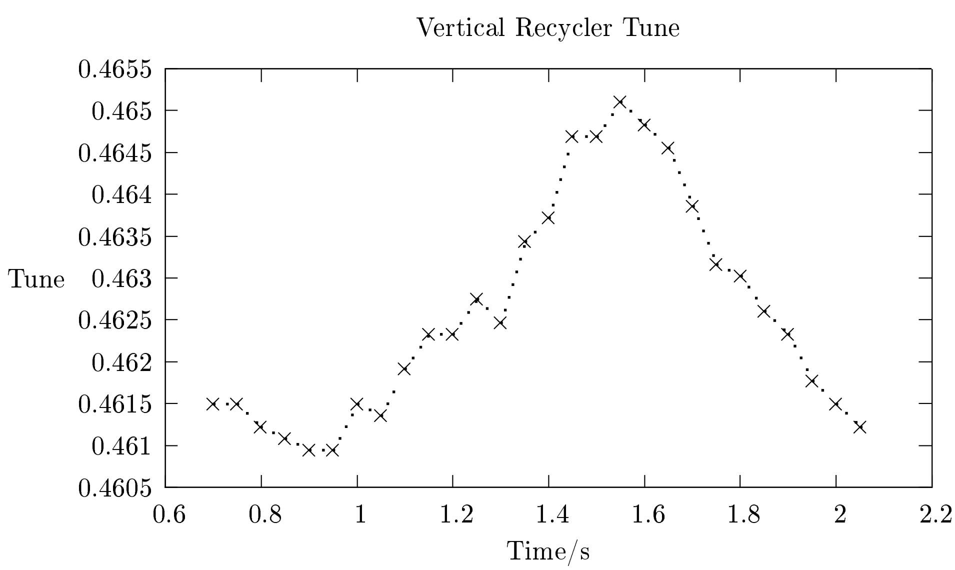

Figure 6: Vertical Tune vs MI Ramp Time

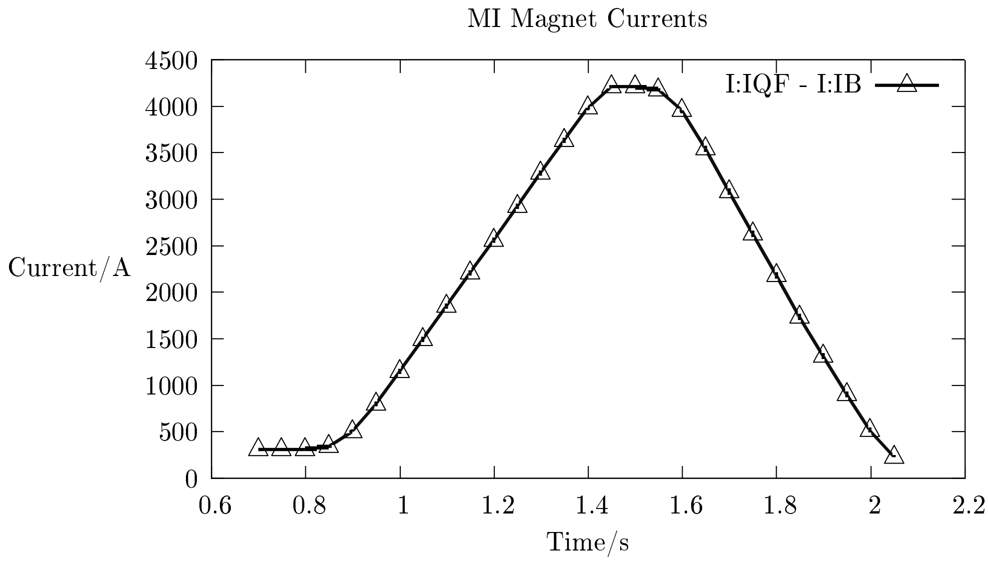

Figure 7: MI Bus Current Differnce vs Time

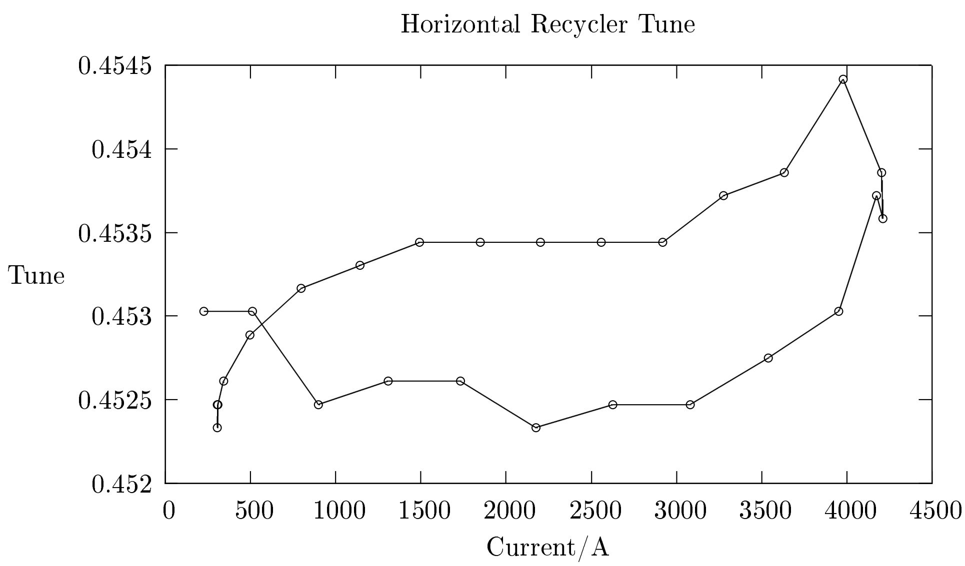

Figure 8: Horizontal Tune vs Current

5 Discussion

5.1 Gate Width

Unfortunately, it seems that the few data sets that we took for this study were somewhat inconclusive. As one can see from the above gate width data, there are what seem to be trends in each data set, but there is no minimum gate width at which one can confidently say that the resolution is fine enough to offer a steady tune reading. It seems that more data will have to be collected, possibly down to gate widths of less than .05 s. Also, to reduce noise in the reading, more than 20 averages may need to be taken for each point. There is plenty of room for improvement in this reading.

5.2 Gate Time

From the data collected regarding the time-dependence of the Recycler tunes, we can easily see that there is a very strong connection between the shift in tunes and the bus currents in the Main Injector. When we do a basic linear interpolation to plot the two sets of data against each other, we find a nice correlation. Figures 8 and 9.

As we can see, the vertical correlation seems relatively linear, while the horizontal looks to be less of a clear fit. One interesting find is the cyclic nature of the data. The horizontal tune data begins at .4525 and cycles with the

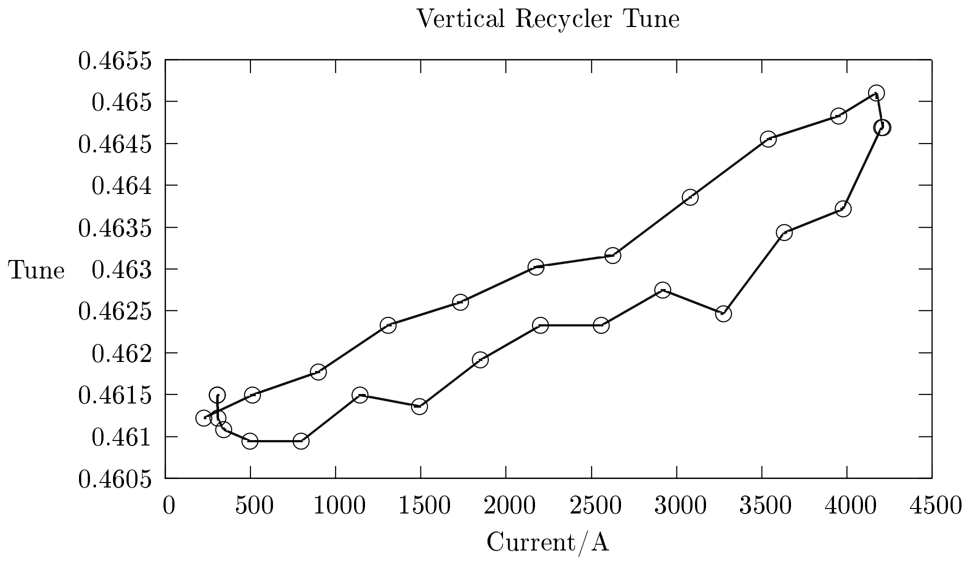

Figure 9: Vertical Tune vs Current

the current buses back to near its original position, and the vertical tune starts at .4615 and goes through at similar cycle. However, they round their cycles in *opposite* directions, with the horizontal tune drifting higher on the rising edge of the amp than on the falling edge and the vertical tune doing the opposite. Also worth note is the fact that the vertical tune drifts across a range that is almost twice that of the horizontal tune.

There is still quite a bit to be learned from this data, although it will probably require several more data sets to be collected, perhaps on more specific parts of the ramp.