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FURTHER MEASUREMENTS OF BEAM-BEAM INTERACTIONS IN A GEAR-CHANGING SYSTEM IN DESIREE*

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Abstract

In this work we detail experiments performed on a gear-changing system using the Double ElectroStatic Ion Ring ExpEriment (DESIREE). A gear-changing system is one where there are different harmonic numbers in each ring. This experiment used carbon and nitrogen beams in a 4 on 3 gear-changing arrangement, with the last bunch of each left off. The bunch length can be measured and synchrotron motion detected. We performed this measurement on three different values of carbon current, and present the differences in the bunch length frequency spectrum here. The frequency difference corresponds to twice the synchrotron frequencies.

INTRODUCTION

This work was performed as a part of a larger project called Direct Observations in DESIREE of Gear-changing Events (DODGE). This program has used the Double ElectroStatic Ion Ring ExpEriment (DESIREE) to demonstrate gear-changing in an operational accelerator [1][2]. Gear-changing is a type of collider synchronization method where the two rings of a collider each have a different harmonic number of bunches [3]. In the experiments shown here, we had one carbon beam with four bunches colliding with a nitrogen beam with three bunches moving at 4/3 the velocity of the carbon. DESIREE sends both bunches in the same direction, usually at the same velocity to study ionization reactions [4]. In our experiment the velocity difference leads to collisions in a moving reference frame. A diagram of DESIREE is shown in Fig 1.

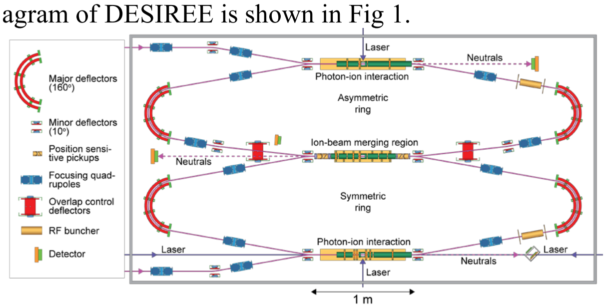

Figure 1: This is a schematic view of the DESIREE machine.

In this work we expand on previous experiments that were able to demonstrate a gear-changing system for over 37,500 turns (~1s) and were able to detect measurable longitudinal beam-beam interactions. The purpose of this experiment was to expand on those longitudinal beam-beam measurements by increasing the bunch charges of both beams. By then steadily increasing the charge of the carbon beams we can measure the change in the longitudinal synchrotron motion using bunch length oscillations.

THE EXPERIMENT

We measure these interactions by measuring the bunch lengths and how they evolve over time. This will give us a reading of twice the synchrotron frequency. We can take the evolution of the bunch lengths both with colliding beams, and baseline measurements with only one beam at a time. We then take the Fourier spectrum of each signal and compare them. The data was collected using the pickups at either end of the merger region. In order to measure the beam as it evolves, we use the missing bunch method. This leaves an empty bucket in each ring which creates a repeating pattern, giving us an evolving snapshot of the beam.

Earlier experiments used a curve fitting algorithm to match the BPM signals and extract the bunch lengths and positions. With higher currents, the shape of the bunches is often not well matched by a gaussian. For this work we instead applied a noise filter to the data and then calculated the moments of the distribution directly, treating the oscilloscope readings like a histogram.

We performed three sets of measurements; the plan was to keep the nitrogen current the same throughout the experiment while using three different carbon currents. We recorded 1156 carbon turns, and 1540 nitrogen turns. with collisions, and baselines with just the carbon and nitrogen beams as baselines. The beam parameters were chosen to show a carbon beam of 7, 14, and 21 nA, while the nitrogen beam was intended to keep steady value of 4 nA. The carbon beam was kept at an energy of 7.01 keV, and the nitrogen was kept at 14.3 keV.

EXPERIMENTAL RESULTS

The results of these measurements have shown clearer traces of longitudinal beam-beam interactions than were seen in previous work. This was due to a combination of larger beam currents and longer bunches, which made the uncertainties of the moments smaller.

Bunch Length Data

These higher currents have simplified the measurement of bunch length, and are able to visually show the differences between the bunch length frequency for collisions and for their baselines. This can be seen in Fig 2. In these cases, the data from one of the pickups is shown as a

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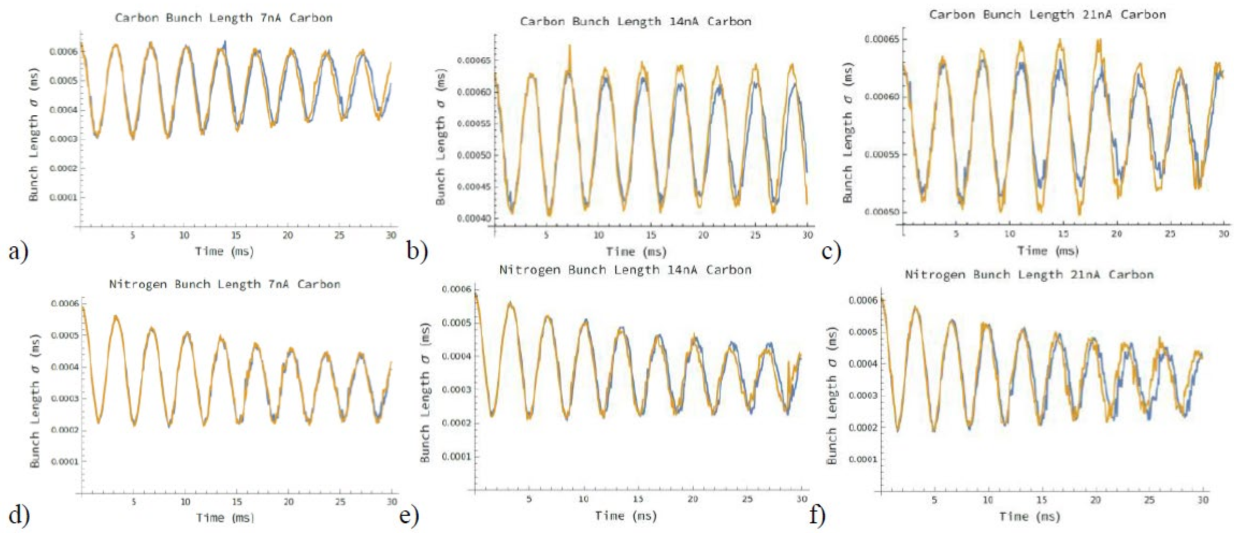

Figure 2: in these plots we see the bunch length evolution for both beams as a baseline (blue) and with collisions (gold).

representative to maintain a clear picture of the curves. We also noticed here that the parameters for the nitrogen beam change slightly between the middle current collision measurement and the middle current baseline. When comparing the total area under the curve for each bunch we were able to conclude that the baseline taken for the low carbon current run could be used for the middle carbon current run. The high carbon current run interacted with a slightly different nitrogen beam but the baselines match the colliding regime for that one. In future experiments we will re-order our data taking to prevent something like this from happening.

Bunch Length Spectrum

If we measure the spectrum of these two sets of data and directly compare them, we will see the identifiable longitudinal tune difference in the bunch length spectrum of the carbon. These can be seen in Fig 3. If we look at the spectrum of the final three quarters of the data, we can see an even clearer spectrum, these are shown in Fig 4. The steadily increasing changes seen in Fig 4 d-f are commensurate with the increase in the bunch charge of the colliding carbon beam.

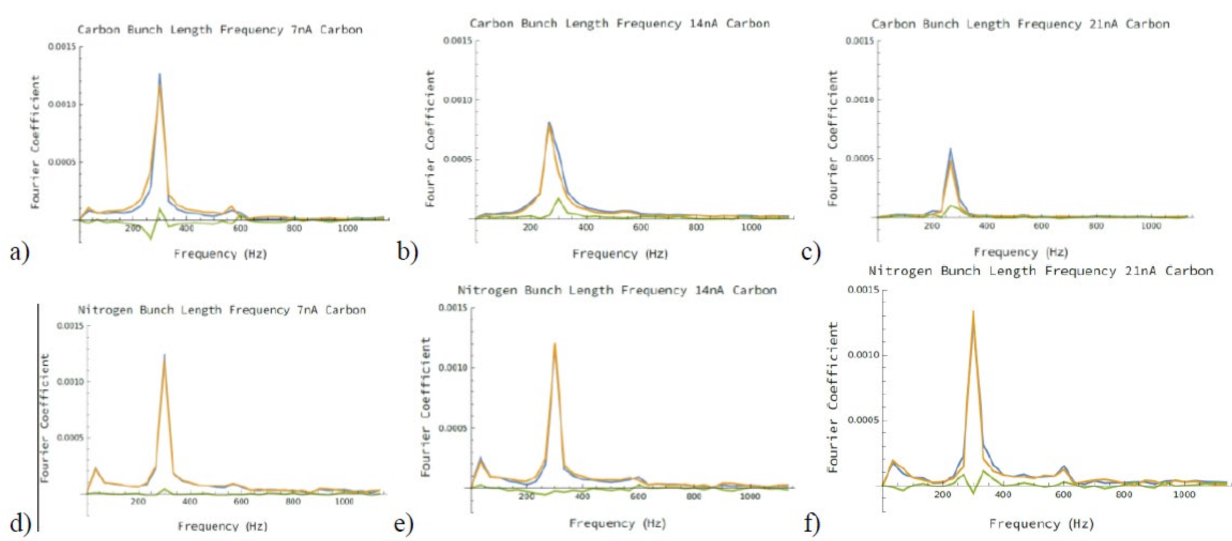

Figure 3: In these plots we see the spectra of the bunch length evolution for both beams, showing the colliding beam (blue) the baseline beam (gold) and the difference between the spectra (green).

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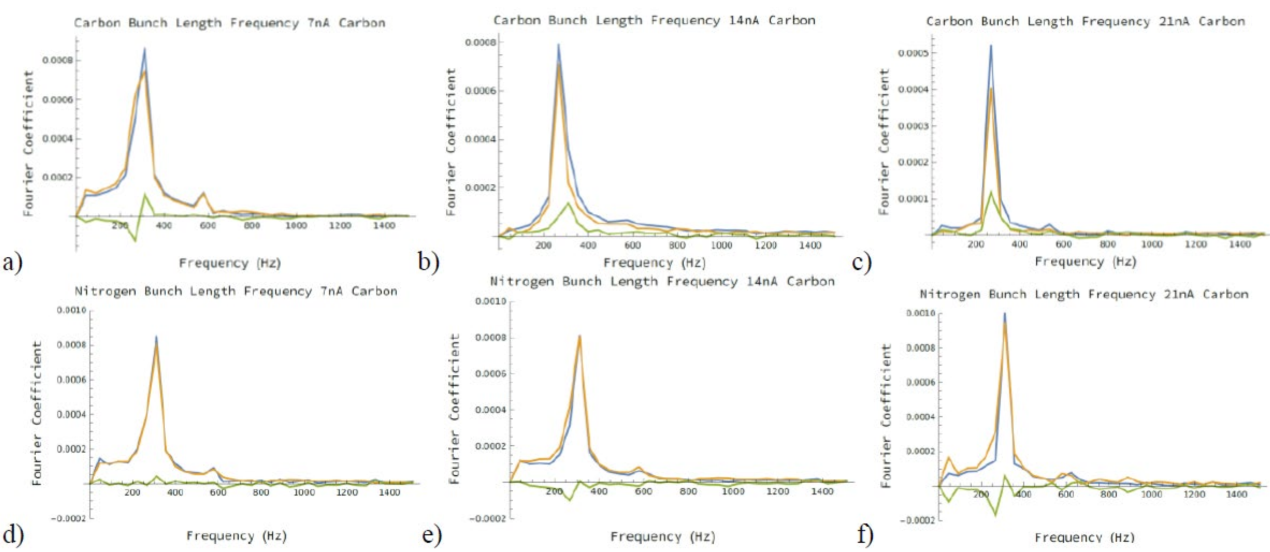

Figure 4: In these plots we see the spectra of the bunch lengths while disregarding the first quarter of the data, this will remove the early portions before the interactions have had a chance to feel the effects of collisions. The color scheme shows the colliding beam (blue) the baseline beam (gold) and the difference between the spectra (green).

DISCUSSION, CONCLUSIONS, AND FUTURE WORK

One of the main issues in this set of data was the actions of the nitrogen beam. The Faraday cup data showed a large spread in the recorded current. Since these pickup traces were made by averaging over 20 samples, it likely would not cause problems with the carbon measurements since on average they would be receiving the same kick. However, this may mean that the nitrogen signals aren't as accurate. We are not sure if this is due to sampling frequency problems, or if the source was unstable. The differences in the spectra based on when we start counting indicates that we should start looking at the beam after a higher number of turns, which is planned for future experiments.

This work was able to again show the bunch length spectrum method is able to detect differences between the bunch colliding beams and the baseline beams. Looking at the differences in the tracings of Fig 1a, 1b, and 1c, suggests that at these higher currents space charge is likely becoming a significant force. This may suggest that there is a practical limit to what charge regimes we can reliably measure. Further work is needed in this regard, as the ability to separate the effects of beam collisions from the effects of space charge are important for any possible gear changing test facility [5], and for any other use case for these types of comoving collisions [6].

This set of experiments used the missing bunch method of removing the last bunch of each beam, thus a 4 on 3 gear changing system is colliding 3 bunches on 2. This allows us to measure the beam as it evolves, but it also changes the nature of the interactions since they do not collide every turn. In the future we intend to remove one beam after a period of time and measure the other throughout a synchrotron period to examine the phase space via phase space tomography.

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