Observations of Effects of Ion Accumulation in the Maxwell Model 1.2-400 Synchrotron Light Source

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Abstract

The commissioning phase of the Maxwell model 1.2-400 synchrotron light source was successfully completed at the end of August, 1992, with more than 200 mA accelerated to 1.3 GeV. This is the first synchrotron light source built by a commercial firm in the U.S. The injector is a 200 MeV linac. Ions trapped in the beam have played a major role in beam accumulation during injection, despite ion clearing electrodes which cover 70% of the circumference. The dependence of the maximum stacked current on the location of ion clearing electrodes and on the applied voltages is discussed. Other observed effects due to ions include the vertical blow-up of the beam at injection as seen on an optical monitor, and beam stability at negative chromaticity. These effects are discussed in relation to some prevailing theories.

Introduction

Ion trapping is a well known phenomena at various electron synchrotron facilities, including Aladdin at Wisconsin[1] and the SXLS at Brookhaven National Laboratory[2]. As a result of consultation with these facilities the Maxwell model 1.2-400 synchrotron [3] was designed with ion clearing electrodes (ICE) covering some 70% of the circumference of the ring. Electrodes were divided into six groups. All electrodes in a given group were placed at homologous positions in the lattice and were powered by the same power supply. The voltages applied to each group could thus be independently varied.

Ions can cause undesired tune spreads and chromaticities which limit the accumulated current when resonances are encountered. The conditioning of the vacuum chamber by synchrotron radiation is thus delayed. However, the comissioning of the Maxwell model 1.2-400 synchrotron light source proceeded rapidly in the presence of ions. Figure 1 shows the stored current at 1.3 GeV versus the number of days spent in commissioning. Judicious control of ions in the beam with ICE's may actually aid the commissioning process.

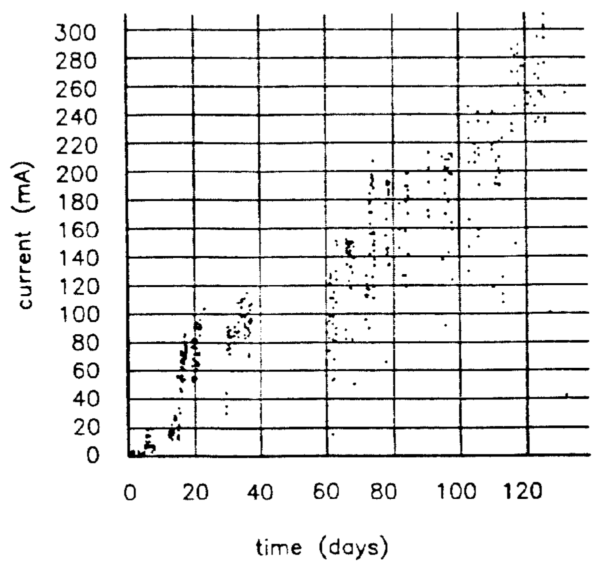

Fig. 1 Initial Current at 1.3 GeV vs. time Since start of commissioning

Ions may stabilize the beam against instabilities to enable a greater stored current at injection. It was observed experimentally that for a given current and pressure, there was always an optimum ICE voltage. A larger voltage would clear ions more effectively, but this actually resulted in less current accumulated. At the same time, the vertical blow-up of the beam was a definite indication that ions are still trapped in the beam even at the optimum ICE voltage.

0-7803-1203-1/93$03.00 © 1993 IEEE

The main section of this paper will describe this and other ion effects more fully in relation to prevailing theories. Due to incomplete data, it is not possible to make detailed quantitative comparisons. But the observations are consistent with general understanding.

1. Observed Ion effects

a. Required ICE voltage as a function of stored current at injection

The required ICE voltage must increase linearly with stored current [2] in order to overcome the beam's self-potential. The exact voltage depends on beam dimensions and the geometry of ICE's within the vacuum chamber. For ICE's located within the dipoles (which were the most effective), it was estimated that for every mA of stored electron current, 6 volts would be necessary. In practice, during initial commissioning about 100 volts were needed just to store 2-10 mA's, and at 200 mA, about 300 volts were needed.

During initial commissioning, the vacuum chamber outgassing is significant. Probably a higher voltage is needed to clear ions rapidly, beyond the necessity of overcoming the beam's self-potential. At higher beam currents, which occurred after about 24 amp-hours of accumulated stored beam time, the fact that less voltage was needed could indicate substantial neutralization.

The experimental observations confirm that the figure of 6 volts/mA is a good rough estimate of the required ICE voltage.

For any given store, an optimum ICE setting is found. The effect of varying the ICE voltage by about 10-20 volts about the optimum on the accumulated current can be illustrated with the strip chart recording of one store as shown in figure 2. The trace shows the reading from a DCCT (Direct Current Current Transformer) in the synchrotron versus time. Current is continuously injected from the Linac at a repetition rate of 0.5 Hz. (The damping time is 1.5 seconds)

With a constant ICE voltage applied, the stored current rises linearly with time initially and then "saturates". Subsequent changes in the "saturation" level are caused by changes in the ICE voltage of about 10-20 volts out of 200-400 volts. This shows how sensitve the stacked current is to the ICE voltage. Such small voltage changes cannot clear the beam of ions. Rather, this suggests fine adjustments in the ion density within the beam.

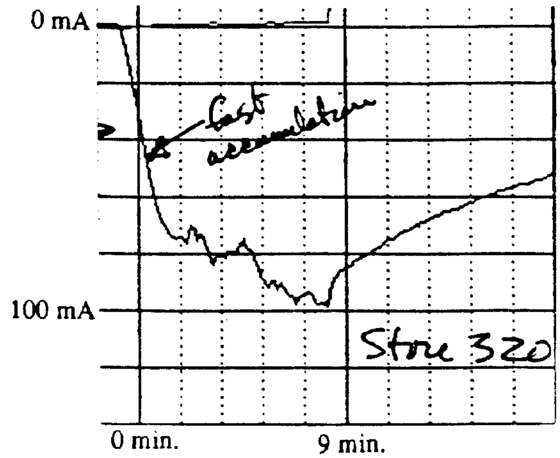

Fig. 2 Effect of ICE voltage adjustment on stacking

b. Location of most effective ICE

According to theory, ions tend to be trapped at sites along the circumference where there is an abrupt change in vacuum pipe geometry since a potential well is formed. For the Maxwell model 1.2-400, the dipole chamber to short straight section transition meets this criterion. The dipole chamber is rectangular in cross-section, with a vertical aperture of 50 mm, while the straight section is a round pipe with an inner diameter of 65 mm. Moreover, this location is where the beam size is minimum so that the beam potential is maximum.

It was found that the dipole ICE's were indeed the most effective in terms of controlling ions. Varying the dipole ICE voltage had the most significant effect on the amount of accumulated current, whereas most other ICE's had little effect. The dipole ICE's consisted of single flat plates located near the chamber bottoms. A negative voltage with respect to the vacuum chamber was applied.

During the initial period of commissioning, some of the dipole ICE's were shorted out. Their subsequent repair led to further increases in the current stacked. This suggested that ions were present and had to be controlled throughout the entire ring.

c. Gaps in bunch train

It has been shown [4] that a gap in the bunch train can significantly improve the performance of a synchrotron by reducing the ion density. In this theory, the nearly stationary ions are periodically focussed by the electron bunches encountered. Whether ions are captured or not depends on whether their motion in this periodic lattice is stable or not.

For a given bunch fill pattern , one can calculate the critical mass of an ion which would be captured. Ions with lighter mass are not trapped. For the Maxwell model 1.2-400, a completely filled ring has 92 bunches. At a beam current of 100 mA and if only 50 buckets are filled, the critical mass was calculated to be about 0.01 (atomic weight). Typical ions are H_2, CO or CO_2 which all have much larger masses. Therefore all such ions are predicted to be trapped.

Since ions should be captured even with a gap in the bunch train present, the ring was run with 50 as well as 92 bunches. As expected, the accumulated current was the same in both cases.

d. Vertical and horizontal coupling

Significant horizontal to vertical coupling was caused by ions. This was most easily observed at 1.3 GeV. At this beam energy, the ICE voltage could be set to zero with no reduction in stored beam lifetime. The beam spot within a dipole chamber was imaged by a TV vidicon through optics arranged such that only the visible portion of synchrotron radiation was detected. What is observed is that the vertical beam size more than doubles to become equal to the horizontal beam size.

At injection energy, the observation was less direct since the ICE voltage could not be turned off without losing beam. However, it is seen that as the current increases, the beam spot gradually evolves from a horizontal ellipse to nearly a round spot. By inference from the observations at 1.3 GeV, more ions are being trapped as the beam current increases.

e. Chromaticity correction

It was found that the sextupole strength needed to attain zero chromaticity was about half of that predicted. This was not directly verified to be caused by ions. However, given that ions are trapped in the beam and that they form a non-linear lens, this is the most likely explanation.

Summary:

In the MLI model 1.2-400, various ion effects have been observed. The locations of ions pockets and the necessary ICE voltages can be estimated by theory. At any time, there exists an optimal ICE voltage for the most accumulated current at injection. At this optimal ICE voltage, some ions are still trapped in the beam. This suggests that ions may be beneficially stabilizing the beam. This is consistent with the experience at SXLS [2]. It has been conjectured that the tune spread caused by ions and consequent Landau damping may be the reason for this stabilization. Further analytical work is needed.

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