The Influence of Fill Structure on Electron Beam Characteristics in the SRS.

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Abstract

It is well known that the stability of ions in an electron storage ring is highly dependent upon the fill structure around the circumference. The consequence of running the SRS with different fill structures has been examined in detail. Results are presented of measurements of beam profiles, higher order mode spectra and other related parameters. These experiments confirm the importance of ion trapping in the behaviour of the 2 GeV electron beam and demonstrate the advantage of running the SRS operationally with an optimised gap in the circulating beam.

1. INTRODUCTION

Many storage rings now operate routinely with a non-uniform fill pattern. At the moment the SRS still usually operates with all 500 MHz bunches filled equally. Source size variation with beam current is observed in the SRS and has been attributed to ion capture [1]. In an effort to control these ion effects the SRS has been operated recently with various fill structures.

All of the patterns investigated have a number of consecutive empty buckets with the remainder filled as evenly as possible. These fill patterns have been attained by using a timing system controlling the injection from the booster synchrotron to the storage ring and not by knocking out bunches. This method does not provide a particularly smooth fill as it is dependent upon the fill structure in the booster. A typical example is shown in figure 1.

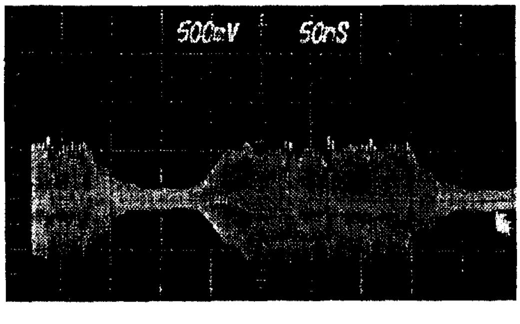

Figure 1. Scope trace from a pick-up strip in the SRS. The fill structure shown has approximately 40 empty buckets.

2. ION THEORY

The circulating electron beam interacts with the residual gas in the vacuum chamber producing low energy ions that can become trapped in the potential well of the electron beam. The existence of trapped ions can be one of the primary beam quality limitations for electron storage rings (increased emittance, reduced lifetime etc).

Trapping of ions can be modelled by representing the passing electron bunches by a thin lens model [2]. With uniform bunch spacing and charge density this linear approximation leads to a critical mass-to-charge ratio above which ions perform stable oscillations and can become trapped. For the SRS this model suggests that at a nominal current of 200 mA all ions are stable with all buckets filled equally.

The introduction of a succession of empty buckets into the bunch train alters the stability criterion for the ion. In this case a number of stable and unstable mass bands are created that shift with the beam current [3]. In general, as the number of consecutive empty buckets is increased the regions of instability increase, leading to decreased likelihood of ion trapping. In addition, since the bunches in the SRS have a rather unequal population (figure 1) this will have the useful effect of presenting random gradient errors to the ion motion [4].

3. EXPERIMENTS

3.1 Beam Profile Measurements

The main reason for running the SRS with different fill patterns is to reduce the influence of ions. One of the clearest ways of assessing the effectiveness of a particular fill structure is by monitoring the electron beam profile. At Daresbury these are measured by imaging the visible synchrotron radiation onto a pair of photodiode arrays, one for each axis [5]. The system is fully automatic and is generally allowed to run for approximately 24 hours at a time taking profile data every few minutes.

The best way to assess the effectiveness of a particular fill structure is to allow the electron beam to decay naturally over several hours while closely monitoring the beam characteristics. This technique may mean each experiment taking many hours. However, it gives a more accurate picture than scraping the beam out artificially to speed up the experiment because the equilibrium between the electron beam and the ions is not disturbed. A good compromise is to allow the beam to decay naturally for a few hours at typical user beam currents and then to scrape the beam out in stages down to low current to complete the picture.

The beam size for three 2 GeV electron beams with a different number of RF buckets filled in each is given in figure 2. These beams are all setup under nominal user conditions. Both superconducting wigglers are on at full field and the undulator is at minimum gap. The DC ion clearing electrodes are on at their standard level of -600 V.

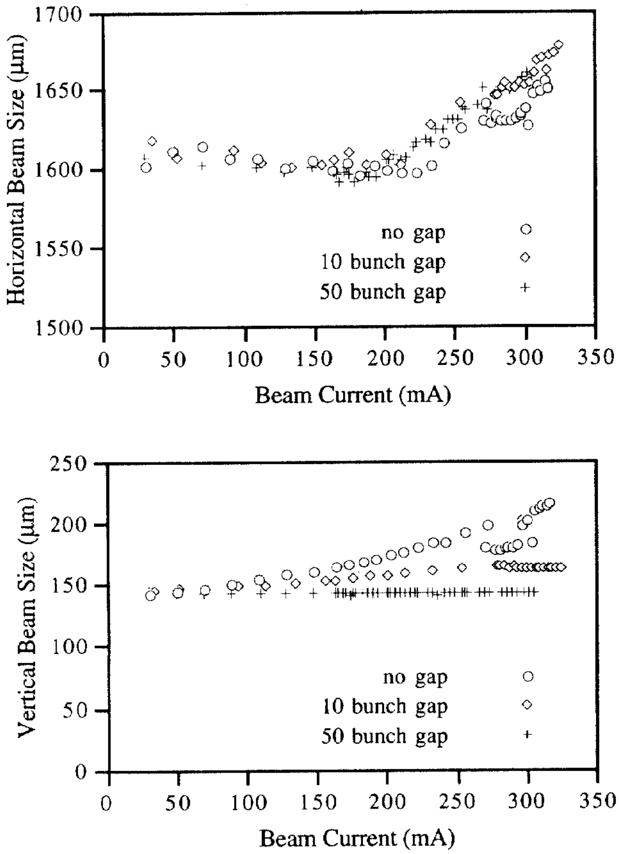

Figure 2. Horizontal and vertical beam profiles for beams with different fill structures.

The effect of the three different fill structures is very striking in the vertical plane. For the beam with all 160 RF buckets filled there are step-like changes at high current. It is interesting to note how a gap of 10 consecutive bunches reduces the vertical beam size but does not totally remove the variation with current. It appears that a gap of 50 bunches removes all variation of vertical profile and the computed zero current beam size is measured at all beam currents.

The horizontal plane shows no significant difference between the three fill structures. The increase in profile width above about 200 mA is thought to be due to a change in energy spread of the beam.

3.2 Higher Order Mode Spectra

Another useful diagnostic for assessing the influence of a particular fill pattern is to monitor the spectral frequency components of the electron beam. The fill pattern with empty buckets will generate orbit harmonics which are not excited by a smooth evenly filled beam. To check that no harmful higher order modes are excited by the beam the frequency spectrum has been closely monitored during all the experiments. Although the spectrum does show variation with different fill patterns these are as expected.

3.3 Ion Clearing Voltage Effect

Each of the 16 dipole vessels in the SRS contains conducting plates above and below the beam. These plates are used for ion clearing by applying a DC voltage across them. During routine operations this voltage is set to -600 V. The importance of these electrodes has been reported already for the case where every bunch is filled equally [1]. Further work has now been completed that examines the importance of these ion clearing electrodes under different fill patterns. The vertical profile is shown in figure 3 for two different 2 GeV beams. The first has all 160 bunches filled and the second has a gap of about 40 bunches. Both beams were allowed to decay naturally for several hours with the clearing electrodes set to zero volts.

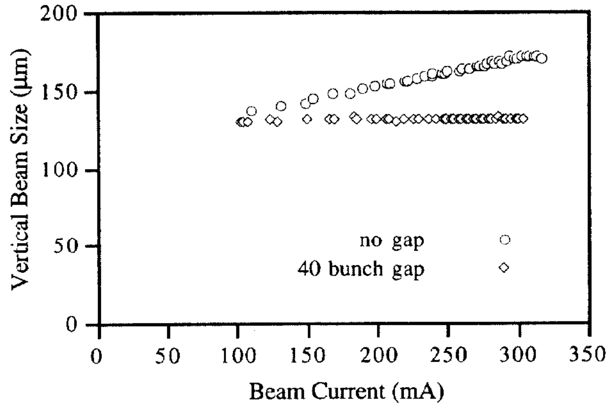

Figure 3. Vertical source size as a function of beam current for different fill structures. The ion clearing electrodes are set to zero volts.

By comparing figures 2 and 3 it is interesting to observe that the beam with a 40 - 50 bunch gap behaves similarly whether or not the clearing volts are applied. This encouraging result implies that the altered fill structure alone is sufficient to destabilise any ions. In this mode of operation the ion clearing voltage is not required. Note the surprising result that the vertical profile with no gap also appears better when the ion clearing volts are at zero. This is due to the quite different vacuum conditions for the two experiments. A thorough assessment illustrating the necessity for ion clearing electrodes in the no gap mode is given in reference [1].

3.4 Lifetime Measurements

One concern of running the SRS with an altered fill structure is that of lifetime. The inevitably increased peak bunch currents with gapped beams (for the same average circulating current) could reduce the normal lifetime since it is known that at 2 GeV single bunch lifetime in the SRS is limited by the Touschek effect [6]. During a short operations trial of running with a ≈40 bunch gap, the beam lifetime was closely monitored. Figure 4 shows the lifetime for several consecutive beams measured at 200 mA. Clearly in this case there was little difference between the two fill structures. However, this data was taken when the vacuum in the SRS was quite poor due to a leak on a cooling water feedthrough. Under these conditions the gas scattering lifetime is dominant and any change in Touschek lifetime may not have been detectable. This data will have to be repeated under improved vacuum conditions for confirmation that any Touschek lifetime change is not significant.

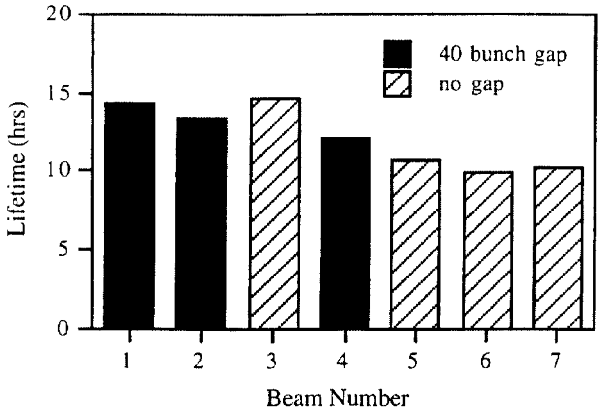

Figure 4. Beam lifetime for seven consecutive user beams measured at 200 mA.

4. CONCLUSION

It has been demonstrated that running the SRS with around 40 consecutive empty bunches has many advantages. Amongst these are a reduced and constant vertical source size with beam current and the removal of the need to run with any clearing electrode volts. No disadvantages have been observed though final lifetime checks are still required as is confirmation that there are no unexpected RF heating effects. It is envisaged that when these final tests have been carried out the SRS will run with this fill structure routinely for users.

The current method of obtaining different fill patterns is dependent upon the injection timing system. For operational use a more elegant method would be RF knockout in the storage ring. Preliminary trials have begun into this technique. This method would have the added advantage of allowing the investigation of more varied fill structures which are as yet impossible to obtain in the SRS.

5. REFERENCES

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