Source Size Variation and Ion Effects in the SRS at Daresbury

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Abstract

Source dimensions in the electron storage ring are routinely monitored on a diagnostic beam line. During recent recommissioning of the SRS, following the installation of a second wiggler magnet, relatively poor vacuum conditions were experienced. Large step changes in source size have been measured and broad tune signals have been seen, together with other effects characteristic of ion influences. Changes of source size and beam stability as a function of ion clearing electrode voltage have also been observed. This paper summarises all such effects observed and comments on their probable causes. It also includes other data on source dimensions, such as measured emittance coupling and the effect of insertion devices in the lattice.

I. INTRODUCTION

The source size of the stored electron beam in the SRS is monitored routinely and now uses a fully automated computer data acquisition system. Recording the beam profiles during every stored beam has brought to light some interesting patterns of source size behaviour. This paper summarises some of the results obtained recently. Of particular interest is the way in which positive ions appear to affect the beam. This paper emphasises the results that show such ion dependent phenomena. After a recent vacuum system let-up, for the installation of a second superconducting wiggler magnet [1], relatively poor vacuum conditions existed as the vacuum system reconditioned. The opportunity was taken to study alternative methods of controlling ion behaviour.

II. SOURCE SIZE DIAGNOSTICS

The SRS has a dedicated diagnostic beamline which monitors the visible synchrotron radiation emitted by the stored electron beam. This diagnostic facility has been described in detail elsewhere [2]. The beam profiles are measured by imaging the visible synchrotron radiation onto a pair of photodiode arrays, one for each axis. Recently the system has been expanded to include computer controlled data acquisition. The output of the arrays is read into a Macintosh computer controlling a range of instruments. This allows accurate curve fitting to be carried out on the data. The system is fully automated and is generally allowed to run for periods of approximately 24 hours. All of the software is written using the commercial software package LabVIEW [3]. LabVIEW is a graphical programming system for data acquisition, analysis and presentation. By assembling graphical software modules in the form of block diagrams the programmer avoids the need for cumbersome text-based code.

III. SOURCE SIZE VARIATION

A. *Typical Beam Behaviour*

The beam profiles are recorded routinely during every operational stored beam period. On the SRS typical starting currents are of the order of 250 mA after being ramped to the full energy of 2 GeV. The beam lifetime is generally around 25 hours. All of the 160 rf buckets are filled.

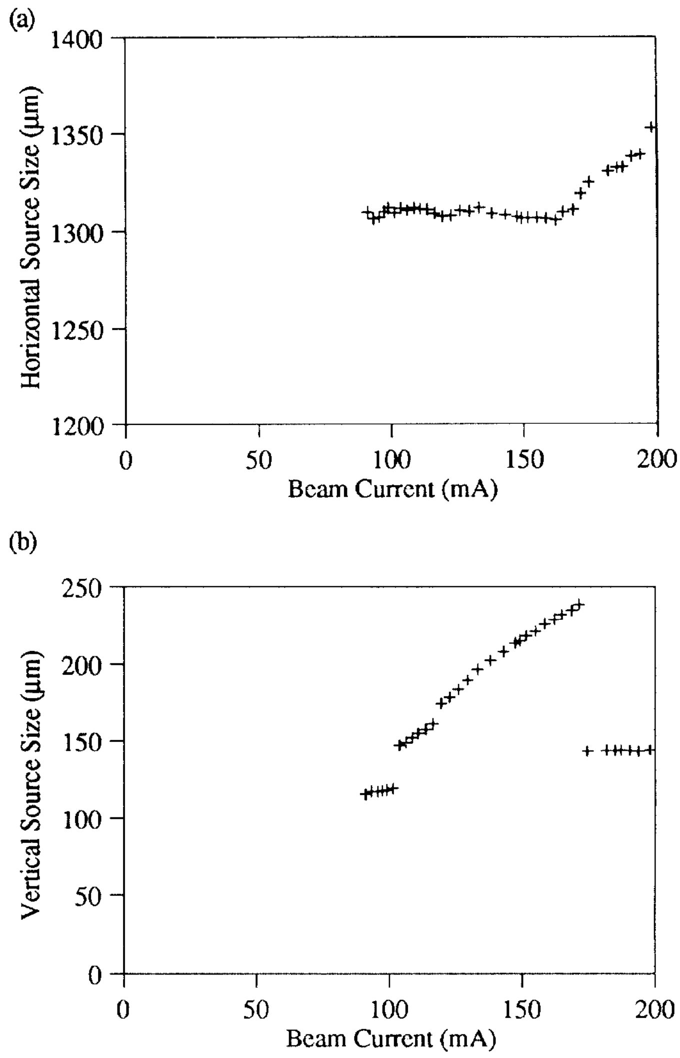

Figure 1. Typical horizontal (a) and vertical (b) source size measurements on the SRS at 2 GeV.

After opening the vacuum system to install the second superconducting wiggler magnet in early 1992 the residual gas pressure in the SRS was relatively high ($\approx 7 \times 10^{-9}$ Torr). This led to some interesting changes in profile during periods of stored beam. A typical example of how the profile varied as the current decayed is shown in Figure 1. Note how the

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vertical step change appears to coincide with a levelling off of the horizontal profile. The step like changes apparent in the vertical profile are thought to be due to ion species trapping and detrapping. This behaviour has been observed to become less common as the vacuum has improved ($\approx 3 \times 10^{-9}$ Torr). It is usual for the vertical profile to decrease in a smooth fashion as the beam current decays at lower pressures and presumably less ions, however the horizontal profile does still show some unpredictable behaviour.

Clearly unusual behaviour cannot be automatically attributed to ions. A rigorous exercise was undertaken to identify and eliminate other possible causes. On the SRS there are two well established working points in betatron tune space (one for high emittance and one for low). The unpredictable beam profile behaviour has been observed at both working points. No coherent signals are associated with the phenomena which points away from certain instabilities. Also, the betatron tune signals observed with a pick-up are relatively wide at higher residual gas pressures, particularly in the vertical plane (±0.008 compared with ±0.001 at lower pressures).

B. The Influence of Ion Clearing Electrodes

Ion clearing electrodes are installed above and below the beam orbit in each of the sixteen dipole vessels. These are used routinely during operations. To demonstrate the necessity to operate with the electrodes on, the electron beam profiles have been recorded during the decay of a 2 GeV beam under typical operating conditions with and without the clearing voltage applied. The vertical source size for the two cases is shown in Figure 2. In this case a clearing voltage of -500 V has produced a significant reduction in vertical profile and with lower point to point scatter. Clearly the ion clearing electrodes are necessary for minimising the influence of ions on the electron beam.

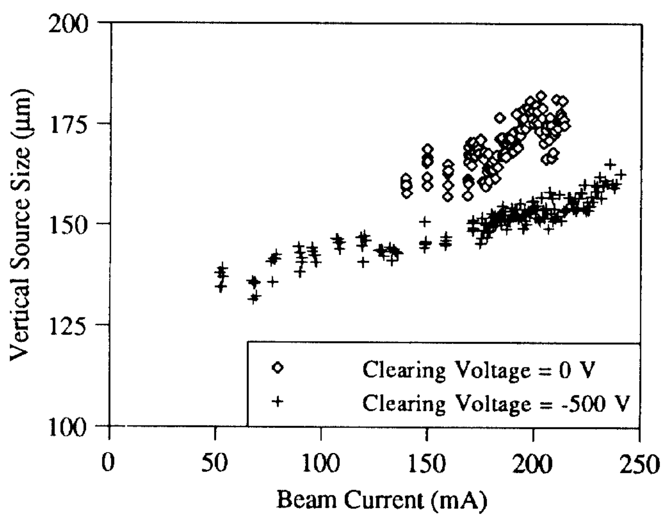

Figure 2. Vertical source size as a function of beam current for different ion clearing voltages.

A more extensive optimisation than can be detailed here has been undertaken of the actual routine value to be used for the clearing voltage. This has found that most of the benefit is gained from the first -100 V but additional voltage does have a useful effect. In general the ion clearing electrodes are used at a level of -600 V.

C. Different Fill Structures

It is well known that the trapping of ions depends greatly upon the fill structure employed. By leaving a number of consecutive rf buckets empty during injection the threshold current for ion capture can be greatly reduced. The influence of the fill structure on the beam dimensions has been investigated on the SRS. A beam was injected with approximately 30 of the possible 160 rf buckets filled consecutively. At 2 GeV typical operational conditions were applied and the beam was allowed to decay naturally. The source dimensions were compared with those of the next two normal operational beams which both had all 160 bunches filled. Note that for all of these beams the ion clearing electrodes were employed at their nominal value of -600 V. The vertical profiles obtained are shown in Figure 3. It is clear that the vertical source size is highly influenced by the fill structure as expected. Simple linear theory has confirmed that with all buckets filled then all ions can be trapped whereas with a large gap of around 130 buckets only ions with a mass to charge ratio greater than ≈50 will be readily trapped by the electron beam at over 100 mA.

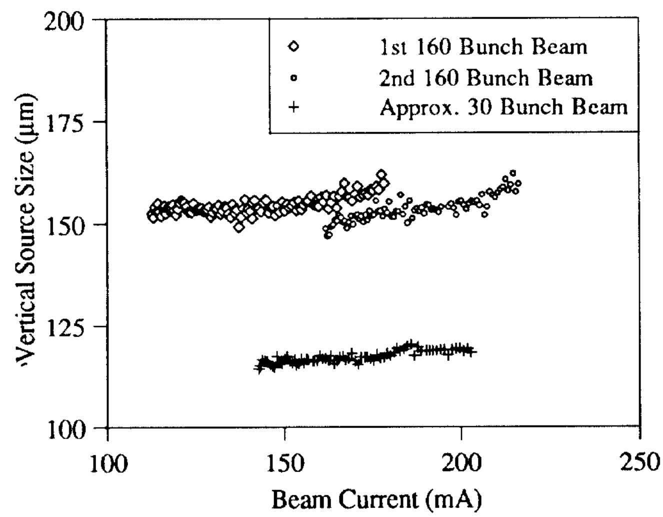

Figure 3. Vertical source size as function of beam current for different fill structures.

D. Insertion Devices

There are now three insertion devices installed in the SRS, one undulator and two superconducting wigglers. The undulator has a minimal effect on the source size but the wigglers should have a significant effect. The beam profiles have been recorded as the 5 T wiggler is energised. The wiggler ramp was paused at a number of field values and several sets of profiles recorded at each one. The betatron tune change induced by the wiggler was minimal since a compensation scheme is in use although this does leave some residual beta function modulation [4]. The results of the experiment are shown in Figure 4. Unexpectedly the vertical source size actually decreases as the wiggler field is increased to 5 T.

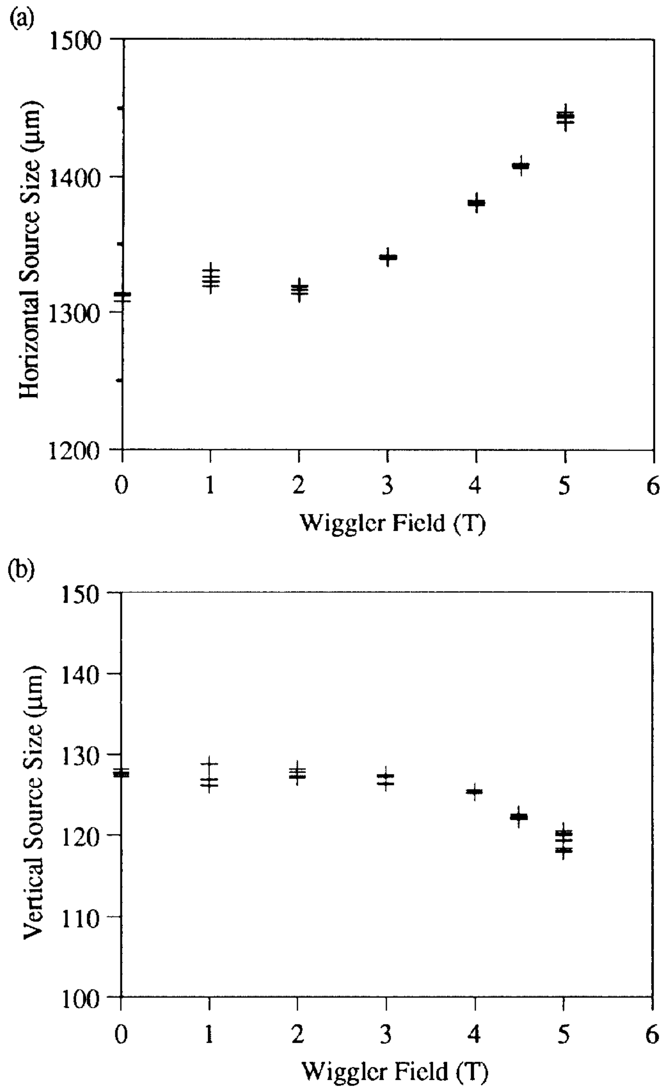

Figure 4. Horizontal (a) and vertical (b) source size variation as a function of wiggler field. The beam current was 100 mA.

A lattice model has been used to predict the theoretical effect of the wiggler. Our in-house code ORBIT [5] predicts that the emittance should increase by ≈25%. In a simple model the emittance increases with the integral of the B-field cubed. This is clearly reflected in the figure. Since the vertical beam profile actually reduces it is assumed a slight decrease in the emittance coupling must be induced by the wiggler. By using values of beta functions and dispersion function from the lattice model it is possible to estimate the change in the apparent emittance coupling. The coupling with the wiggler off is 2.8% whereas with the wiggler on at its full field of 5 T it is 2.3%. The newly installed 6 T wiggler has now been commissioned [1] and early indications are that the source size changes will be of the same order as for the 5 T wiggler.

IV. CONCLUSIONS

It has been demonstrated that under relatively poor vacuum conditions the source size exhibits step like changes which have been attributed to ion trapping and detrapping. Following these observations several experiments have been carried out to study the influence of the ion clearing electrodes and the beam fill structure on the source dimensions.

It has been shown that the influence of ions is significantly reduced, in terms of source size, by the application of the ion clearing electrodes. The fill structure of the beam has also been demonstrated to be an efficient method of reducing the influence of ions. A roughly 25% reduction in vertical profile has been demonstrated by reducing the number of consecutive rf buckets from the full complement of 160 to approximately 30. Simple linear ion theory agrees that such a change in the fill structure should severely restrict ion trapping. However it would not be feasible to run the SRS operationally in this mode since the lifetime would be too short. This is due to the Touschek effect at such relatively high bunch currents. To maintain a long lifetime it will be necessary to increase the number of buckets, whilst still having sufficient gap to reduce the influence of the ions. Different fill structures will be investigated in the near future.

The 5 T wiggler has been shown to reduce the vertical profile although the radial emittance is increased. This is thought to be due to a slight change in the emittance coupling from 2.8% to 2.3%. It appears from early commissioning work that the effect of the 6 T wiggler on the source dimensions will be of the same order as that of the 5 T insertion device.

Although experiments on ion effects in storage rings are notoriously difficult to assess, it has been demonstrated that ion influences are significant on the SRS. However by using simple techniques, such as ion clearing electrodes and different fill structures, the effect of the ions on the source size can be minimised. At the moment the standard operational stored beam uses all of the rf buckets. More research is required before a new operating regime can be introduced for normal operations.

V. REFERENCES

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