Revised SRS Impedance Estimates

J A Clarke, D M Dykes, S F Hill, E A Hughes, P A McIntosh, M W Poole, P D Quinn, S L Smith, V P Suller and L A Welbourne
DRAL Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK

Abstract

The broad band impedance of the SRS has been previously reported to be about 10 Ω as measured by current dependent bunch lengthening, but to be less than 6 Ω based on both radial beam size and mode shift data if realistic assumptions are made. Recently the bunch length has been measured with a fast photodiode and this gives results about 25 % shorter than with the stroboscopic image dissector previously used. The new bunch lengthening data indicates an impedance in the range 4-6 Ω that is in good agreement with the other methods.

1. INTRODUCTION

A second superconducting wiggler magnet has now been commissioned in the SRS [1] and its installation necessitated major redesign of many of the storage ring injection and vacuum components. Together with an improved septum and kicker arrangement [2] this was expected to have a reduced contribution to the broad band impedance of the ring, previously estimated to be at least 10 Ω based on measurements of vessels in the laboratory [3].

It is now possible to inject and store well in excess of 100 mA in a single 500 MHz bunch in the SRS and this has allowed the impedance effects to be measured over a much wider range than before. Injection at 600 MeV provides a particularly sensitive probe of these effects and attention has been concentrated on the turbulent (microwave) instability and on mode shifts. A previous paper [4] summarised these findings and indicated inconsistencies in the results for bunch length, horizontal size and vertical tune shift. To resolve these issues two further, independent methods for determining bunch length have given results that will be reported here.

2. MODE SHIFTS AND ENERGY SPREAD

The vertical tune shift has been measured at 600 MeV as a function of single bunch current up to 90 mA. Fitting this data to the lowest head-tail mode allows the transverse broad band impedance, Z_t, to be determined. The tune shifts in figure 1 have been normalised to the zero current bunch length in order to allow a linear fit to be made as shown. This gives a value for the impedance of 219 kΩ/m. Assuming an average beam pipe radius of 30 mm in the SRS this can be converted to an associated longitudinal impedance of 6.5 Ω.

This estimate of the impedance can be compared with that derived from the behaviour above the turbulent bunch lengthening threshold. In regions of the lattice with finite dispersion bunch widening then occurs as the momentum spread increases in association with the lengthening bunch. Beam profiles are routinely measured at the SRS based on a system of photodiode arrays and optical imaging on a diagnostic beam line [5]. Using the known lattice functions at the source point the energy spread contribution can be calculated from this data. The measured horizontal beam size at 600 MeV for single bunch currents between 10 and 50 mA is presented in figure 2, with data from several experimental runs indicating some variability in SRS behaviour. This current range is well above the threshold of 1.5 mA predicted by a simulation using the code ZAP [6].

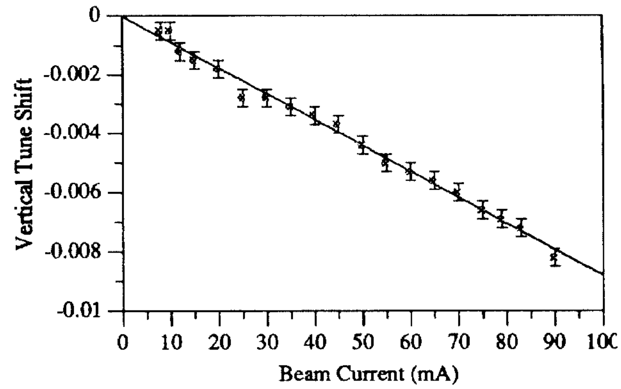

Figure 1. Coherent tune shift with beam current

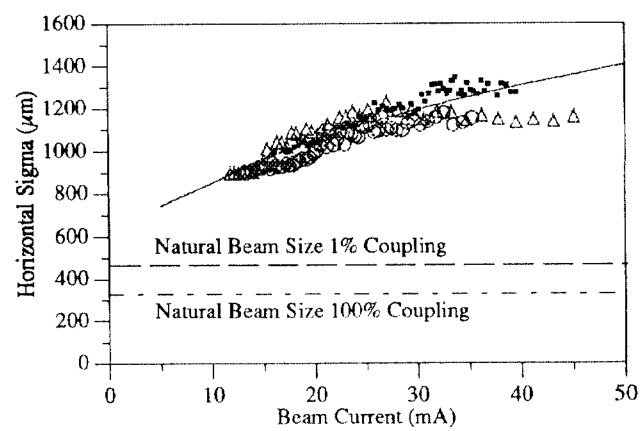

Figure 2. Horizontal beam size variation with beam current

To fit this data to the model it is necessary to subtract the emittance contribution and this requires a knowledge of the coupling in the SRS. Although low coupling (≤5 %) is obtained at the operating energy of 2 GeV the vertical beam size is blown up at the injection level and the coupling is more uncertain : figure 2 includes the full range of possibilities. However the illustrated fit is based on a realistic assumption of 5 % coupling and generates a broad band impedance estimate of 5.5 Ω. This value is in encouraging agreement with the mode shift figure, but not with the 8-10 Ω estimates from more direct measurements of bunch lengthening that have been previously published [4].

3. BUNCH LENGTH MEASURING TECHNIQUES

The bunch length at the SRS is in the region 25-150 ps for most operating conditions and it has traditionally been measured [4,7] with an image dissector pioneered by the Novosibirsk group [8]. This uses the emitted synchrotron radiation to generate photoelectrons that are swept across a narrow slit: applying an rf signal that is phase locked to the circulating electron beam allows the longitudinal bunch intensity to be mapped. A subharmonic of the main 500 MHz is employed and this implies a stroboscopic technique that averages over 16 bunches, so that certain bunch phase oscillations will not be resolved. Nevertheless the instrumentation has provided much useful data and easily resolves the changes arising from various parameters such as current, energy and rf conditions. Uncertainties in the absolute calibration arise from the need to deconvolute effects such as photoelectron transit time and image size at the slit.

As an alternative to this method a fast photodiode has been recently commissioned [9]. This is triggered from a timing button in the ring and gives a more direct method of measurement with less calibration uncertainty, with a resolution of about 25 ps. The results from this were hoped to resolve the discrepancies both with respect to the other impedance estimates and also with some preliminary photon counting results obtained from an SRS user station. Photon counting relies on fast photomultipliers and has a resolution comparable with the photodiode. In principle it should provide reliable data and there was concern that it had suggested bunch lengths somewhat shorter than given by the dissector.

4. COMPARISON OF BUNCH LENGTH RESULTS

An experiment has been carried out to provide a direct comparison between bunch length results obtained simultaneously with the three different methods and the results are given in figure 3.

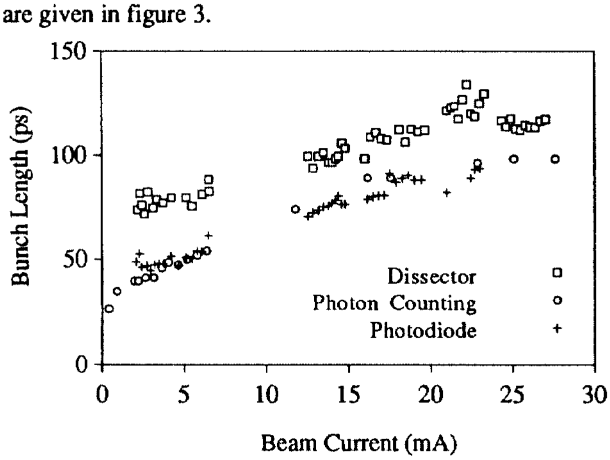

Figure 3. Bunch length as a function of current

As can be seen it has been found possible to make measurements down to extremely low beam currents. In fact the photon counting system was able to go much lower and gave a figure of 23 ps with a circulating beam current of about 1 μA, an excellent confirmation of the theoretical natural length of 21 ps at the chosen parameter settings.

Inspection of figure 3 reveals a good agreement between the photodiode and photon counting data over the full range to 30 mA, but shows a significant and systematic discrepancy in the dissector results. Jitter on the photodiode timing signal is responsible for some asymmetric spread at the lower beam currents. Closer analysis has allowed a correction factor for the dissector data to be determined [9] and this can be used to modify the conclusions on impedance drawn from the earlier bunch length results [4].

5. BROAD BAND IMPEDANCE

The new bunch lengthening results have been fitted in the standard current scaling model [4] and produce revised estimates in the range 4-6 Ω for the longitudinal impedance from 600 MeV data, using either photodiode or photon counting data. An example of such a fit is given in figure 4 and is very close to a third power law as would be appropriate if the impedance does not vary with frequency. This set of data generates an impedance of 4 Ω.

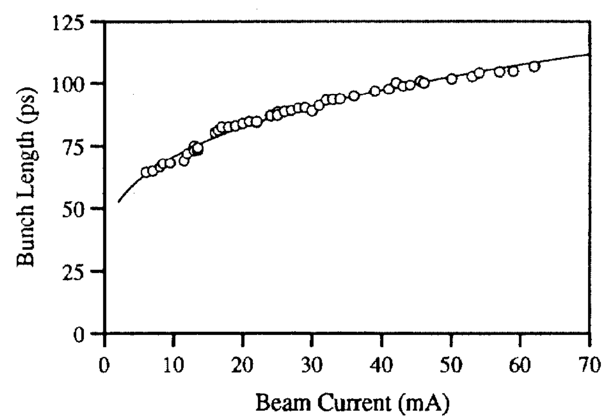

Figure 4. Measured and predicted bunch lengths

The modified impedance is significantly reduced and now in very much better agreement with that predicted from mode shift and beam size calculations. The SRS chamber can be stated with some confidence to have an effective impedance of no more than about 6 Ω, based on the 600 MeV experiments and it may well be as low as 4 Ω. This conclusion is also now supported by the earlier results [4] on bunch length obtained with the dissector : after appropriate correction the best data (extending up to 90 mA) also produces a new figure of 4 Ω.

The opportunity has also been taken to correct the previously reported impedance results at higher energies. An impedance of 4.6 Ω is found at 1 GeV and at 1.5 GeV an increased value of 7.5 Ω, although the smaller amount of data at the latter energy makes that figure much less reliable. Beam currents rarely reach the instability threshold at higher energies and bunch lengthening has never been observed in the SRS at or above 1.8 GeV.

6. CONCLUSIONS

These experiments have demonstrated that extreme care is necessary in the interpretation of bunch length data from a dissector system. The reason for the inaccuracies that have been discovered is still unknown, despite thorough checks of the instrumentation and its calibration procedures. A fast photodiode is now in routine use and a photon counting system is being installed. These latter systems are also necessary so that the SRS operations teams can check that specified single bunch running does not suffer from even low level contamination of other buckets, as can occur if beam stacking is not precisely controlled. When these systems are all commissioned it will be possible to perform accurate measurements of bunch length from about 1 μA up to more than 100 mA in a single bunch in the SRS.

It can now be confirmed that the longitudinal broad band impedance of the SRS vacuum enclosure is in the range 4-6 Ω as determined from three independent experimental techniques, with a best estimate of 4.8±0.5 Ω from 600 MeV experiments where most data exists. This figure is in reasonable agreement with that predicted from the set of directly measured rf impedances prior to the installation of the chamber components in the storage ring, giving confidence that storage ring behaviour can be predicted with acceptable accuracy from such data.

6. ACKNOWLEDGEMENTS

The photon counting equipment was provided by D Shaw, who also used it to carry out bunch length measurements.

7. REFERENCES

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