BEAM LIFETIME AT THE SRS

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Abstract

The beam lifetime in the SRS electron storage ring at Daresbury Laboratory is governed by several processes which vary significantly according to the machine operating mode. A theoretical model of the storage ring has been developed, taking the variable vacuum chamber aperture, dynamic aperture and other effects into account to predict the expected overall beam lifetime. Measurements have been performed to separate the contributions from the different loss processes: Touschek scattering, beam-gas scattering and quantum lifetime effects. Comparison with experiment gives a reasonable agreement with theory in the different operational modes used on the SRS.

1 INTRODUCTION

The 2GeV SRS electron storage ring has delivered synchrotron radiation to users since 1981. In that time, there have been several upgrades, most notably the addition in 1987 of extra quadrupoles to change the lattice from an 8-cell to 16-cell FODO structure to reduce the beam emittance. In addition to the dipole beamlines the storage ring presently includes 2 superconducting wigglers and an undulator; 2 multipole wigglers are planned to be installed in 1998 with reduced vertical apertures [1].

1.1 Lattice Modes

The SRS operates in 2 principal modes. In multibunch mode the lattice is operated with a high radial tune (HIQ) to minimise the emittance. In single bunch operation the Touschek lifetime is maximised by operating with a lower radial tune (LOQ), bringing the working point close to a 2nd-order difference resonance to increase the coupling. Injection from the 600MeV booster synchrotron necessitates ramping to the operating energy of 2GeV. A summary of the lattice properties in the different modes is given in Table 1. Additionally, multibunch operation is performed with both gapped and uniformly filled bunch structures.

Table 1. Lattice properties in HIQ and LOQ modes. Emittances are the theoretical natural values.

		HIQ	*LOQ*
Emittance /nmrad	600 MeV	9	23
	2 GeV	104	258
Horizontal Tune Q_x		6.19	4.21
Vertical Tune Q_y		3.37	3.21
Momentum Compaction		0.029	0.058

The 2 working points operating over a range of energies, coupled with the complex aperture profile through the storage ring, makes the modelling and prediction of the beam lifetime complex. In the following sections a simplified machine model is developed which allows a comparison of theory with experiment.

2 APERTURE MODEL

2.1 Introduction

The many modifications to the storage ring have resulted in a complex vacuum chamber profile. In particular, the upgrade to a higher brightness lattice has meant that several vacuum vessels are larger than they need to be, and the usual assumption that dynamic aperture is consistently larger than the physical aperture is not true in the SRS storage ring. This of course has important implications for any theoretical estimates of lifetimes.

2.2 Physical Aperture Model

A simplified model of the storage ring apertures has been adopted to reasonably approximate the real machine whilst making modelling of proposed changes to the physical apertures more straightforward. Broadly speaking, the model breaks the machine up into 4 sections:

1. Dipole vessel
2. D-Quadrupole vessel
3. Straight section vessel
4. F-Quadrupole vessel

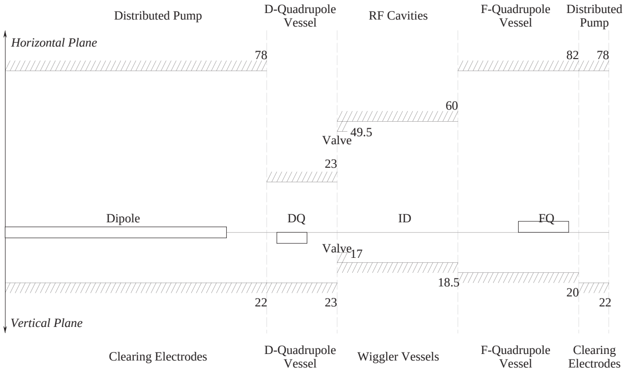

Figure 1. Physical aperture model. The real elements limiting the aperture in each model section are shown for each plane, together with the limiting apertures (given in mm). The positions of the lattice elements are also shown.

The vacuum chamber aperture is assumed to be constant throughout each of these vessels. In addition, a

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vacuum valve on the 6T superconducting wiggler further restricts the machine aperture at one point in the machine; the physical model is summarised in Figure 1. In reality, the largest deviation from this model occurs in the insertion device vessels, where there are different components in each straight such as cavities, beam scrapers, undulators etc.

2.3 Dynamic Aperture

Tracking was performed with a MAD model [2] of the lattice in both the ideal case and with realistic error terms deduced from vertical dispersion measurements [3]; typical closed-orbit deviations from errors are consistent with those observed on the real machine With 40 sample sets of errors it is found that the dynamic aperture is approximately 80% of its ideal value in both the HIQ and LOQ lattice modes. Comparing the on-momentum limits with physical aperture confirms that dynamic limits are significant in the horizontal plane (see Figure 2). Vertically, the dynamic aperture exceeds the physical limit throughout the lattice. In most cases the limiting aperture for Coulomb scattering is in the vertical plane, and so the dynamic limit is not relevant.

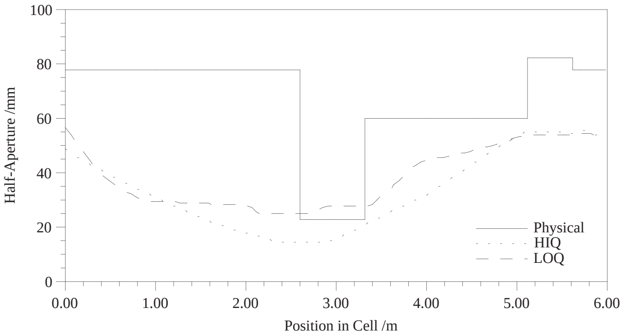

Figure 2. Comparison of physical and dynamic aperture in the horizontal plane in HIQ and LOQ modes. The dynamic aperture is significantly less than the physical aperture in large sections of the machine.

The acceptance limit for off-momentum particles, which determines the Toushek and other gas scattering cross-sections [4], can also come from dynamic limits. Using first MAD to calculate the dynamic momentum acceptance, and then ZAP [5] to calculate the resultant energy aperture, it is found that the dynamic limit is much smaller than the physical limit brought about by the finite lattice dispersion (see Table 2).

Table 2. Physical and dynamic momentum acceptances in the HIQ and LOQ lattice modes.

Mode	*HIQ*	*LOQ*
Physical Limit /%	2.5	1.4
Dynamic Limit /%	0.7	1.1

3 LIFETIME CONTRIBUTIONS

The total beam lifetime is given by the contributions of several effects:

- Beam-beam scattering - Touschek effect.
- Beam-gas scattering from residual gas:
  B - Bremsstrahlung (inelastic) from gas nuclei.
  C - Coulomb (elastic) scattering from gas nuclei.
  I - Inelastic scattering from electrons in residual gas.
  E - Elastic scattering from electrons in residual gas.
- Quantum lifetime limits - this is not significant in the SRS under normal operating apertures.

3.1 Beam Lifetime at 2GeV

3.1.1 Multibunch Lifetimes

At 2GeV the RF voltage of 1.3MV (determined from measurements of synchrotron tune frequency) provides a momentum acceptance of 0.80% in HIQ, meaning that the momentum acceptance is believed to be limited by dynamic effects. The predicted beam-gas lifetimes are shown in Figure 3. At 2GeV the predicted Touschek lifetime is 113 hours with 200mA of uniformly filled beam current (for an emittance coupling of 2.5%); this value changes according to the beam current, the machine coupling and the fill structure. When both Touschek and beam-gas effects are combined in an overall lifetime prediction (using experimental measures of bunch length and fill structure) a reasonable agreement with theory is obtained. An example set of data is given in Figure 4; here the Coulomb scattering component has been varied by changing the limiting vertical aperture with collimators in the storage ring, whilst the other scattering components are constant. The discrepancy may be accounted for if a 30% error in pressure measurement is considered, which is quite reasonable at low pressures.

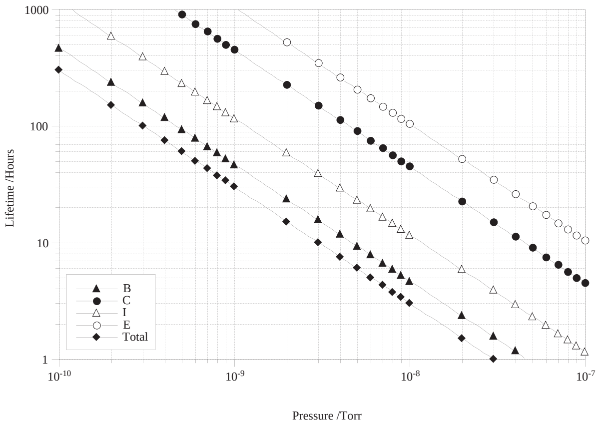

Figure 3. Theoretical beam-gas scattering at 2GeV in the HIQ lattice mode using the physical aperture model. A typical operating pressure in the SRS is around 1nTorr.

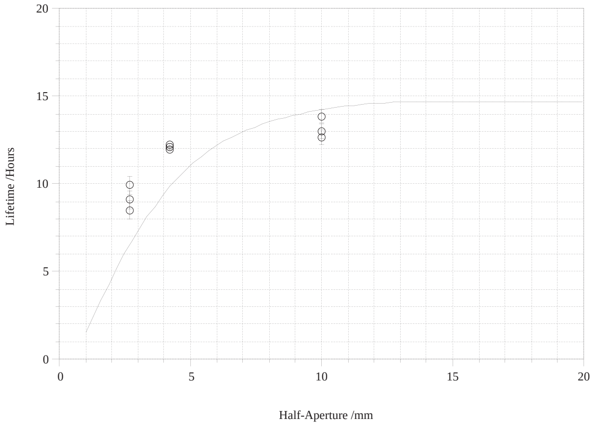

Figure 4. Example of variation of experimental multibunch lifetimes in HIQ with half-aperture at the storage ring vertical collimators. The solid line is the theoretical prediction based upon emittance and pressure measurements.

The increased momentum compaction in LOQ results in a smaller RF acceptance of 0.56%, meaning that the momentum acceptance is RF-limited. The beam-gas scattering contributions are similar to those for HIQ (see above), and varying the vertical aperture with a multibunch beam gives a similar variation of total beam lifetime (see Figure 5).

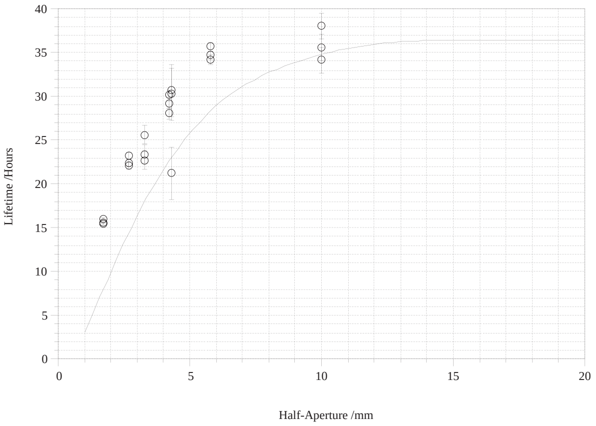

Figure 5. Example of variation of experimental multibunch lifetimes in LOQ with half-aperture at the storage ring vertical collimators. The solid line is the theoretical prediction based upon emittance and pressure measurements.

3.1.2 Single Bunch Lifetimes

With single bunch currents the beam lifetime becomes Touschek-dominated; the RF limit to the momentum acceptance has been confirmed by observing the variation of lifetime with RF voltage in single bunch mode, with a rise from 1.2 to 1.4MV giving ~10% increase in beam lifetime. The variation of the total current-lifetime product with coupling, achieved by varying the distance of the working point from the adjacent 2nd-order resonance, gives a good agreement with calculations of the Touschek lifetime (see Figure 6).

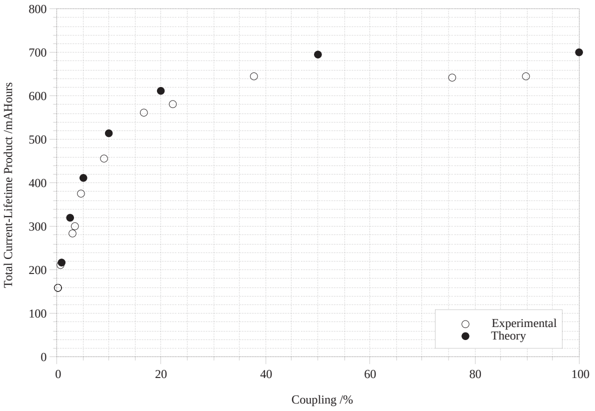

Figure 6. Variation of current-lifetime product with machine coupling for single bunch currents. Theoretical predictions including the gas scattering contribution are also shown.

3.2 Beam Lifetime at 600MeV

At 600MeV in HIQ the RF voltage of 0.4MV gives 1% momentum acceptance, so that dynamic aperture still limits the acceptance. However, even in multibunch the lifetime is strongly Touschek-limited, and with the natural emittance of 9.4nmrad would be around 0.1hours with 200mA of uniform current. This is alleviated by the significant transverse beam blow-up which occurs at 600MeV, which in HIQ corresponds to an emittance around 80nmrad. This raises the Touschek lifetime to around 6 hours; predictions using an increased emittance are consistent with this measurement. A similar phenomenon occurs when injecting at the LOQ working point which helps to maintain the Touschek lifetime in single bunch before energy ramping takes place.

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