Nonlinear Behaviour in the Proposed Lattice of the Daresbury Advanced Photon Source

J A Clarke, J N Corlett*, M W Poole, S L Smith, V P Suller and L A Welbourne
SERC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK
* Now at Lawrence Berkeley Laboratory, University of California, Berkeley CA94720, USA

Abstract

The recently proposed new UK light source design has adopted a racetrack geometry based on a double bend achromat structure with two long super-straights. Dynamic aperture in different operating regions is presented and some comparison made with a symmetric circular ring performance. Field error sensitivity is assessed and the influence of possible insertion devices studied. Emittance growth and beam lifetime have also been estimated.

1. INTRODUCTION

The specification of the proposed advanced VUV/SXR synchrotron radiation source DAPS [1,2] will complement the existing Daresbury SRS facility. The linear lattice properties are described in a companion paper [3] and a comprehensive treatment of the accelerator physics aspects is also available [4]. There is a requirement to operate over a wide energy range (0.5-1.2 GeV) and with a flexible lattice, including alternative modes with high and low betas in its insertion regions. At 500 MeV the performance is at its most vulnerable to the effects of the insertion devices, coherent instabilities and intrabeam scattering processes.

Demonstration of the feasibility of the proposed design has required careful optimisation of betatron tune working points. The racetrack geometry restricts the ring symmetry, affecting the dynamic aperture (DA) through increased resonance line excitation. Tracking studies have used the in-house code ORBIT and established tools such as MAD [5] and RACETRACK [6]. In each case the number of turns is chosen to optimise computing time against accuracy, but often 200 turns has proved adequate away from resonance lines. The tracking utilises 16 starting coordinates in 4-D phase space.

2. CHROMATIC EFFECTS AND ERROR SENSITIVITY

Low emittance lattices have large chromaticities and need strong sextupoles to compensate for this. Nonlinear lattice properties are dominated by this and dramatic reductions in the stable DA can occur. Figure 1 gives DAPS chromaticities in each of the four working regions [3]. These results are a 10 cell circular DAPS example to reference the performance of the basic cells : the two super-straights increase the values by 10-20 %. Minimum lattice emittance coincides with asymptotic radial chromaticity so that it is not a feasible operating mode to choose such a working point. Note also that Regions 2 and 4 exhibit significantly greater chromaticity at optimised working tunes.

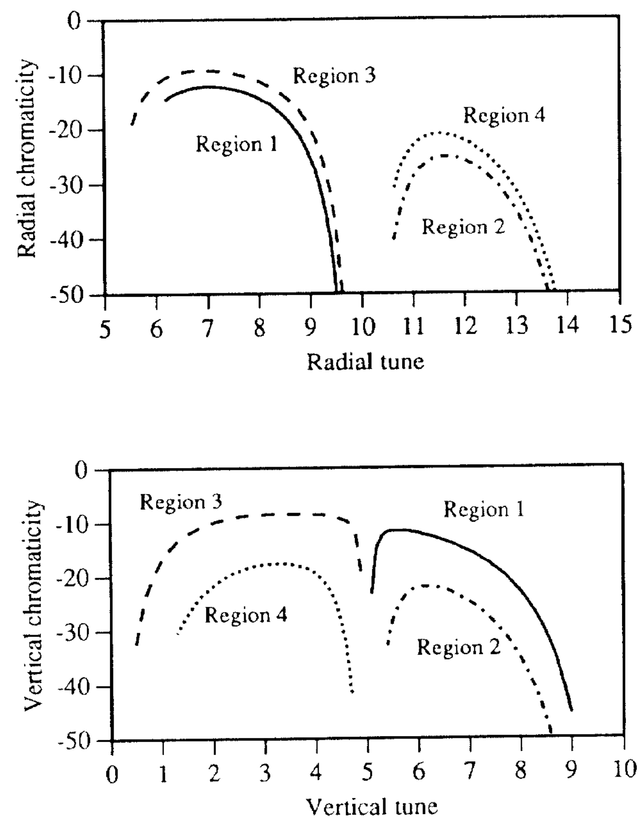

Figure 1. Chromaticity Dependence on Working Point

Stable betatron amplitudes are large for optimised working points in Regions 1 and 3, whereas in Regions 2 and 4 these amplitudes are seriously reduced as would be expected with the stronger sextupoles. Resultant tune shifts for oscillating particles in Region 3 are shown in fig. 2 for radial amplitudes at the insertion straight, with the associated DA in fig. 3. The basic DA for the circular ring is seen to be very large with the racetrack somewhat less. Good lattice performance has been achieved without resort to the inconvenience of additional sextupole families. However it is now widely accepted that nonlinear lattice analysis should include off-momentum behaviour and fig. 4 presents an encouraging result. A more realistic simulation would track electrons with varying energy but this has yet to be undertaken. The nonlinear tune shifts at zero chromaticity are given in fig. 5 and are seen to become significant only at large momentum errors.

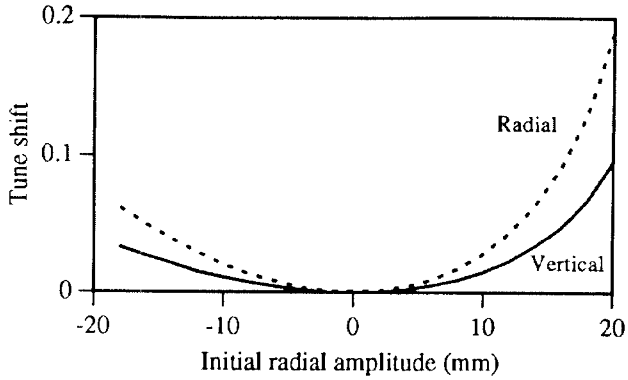

Figure 2. Amplitude Dependent Tune Shifts

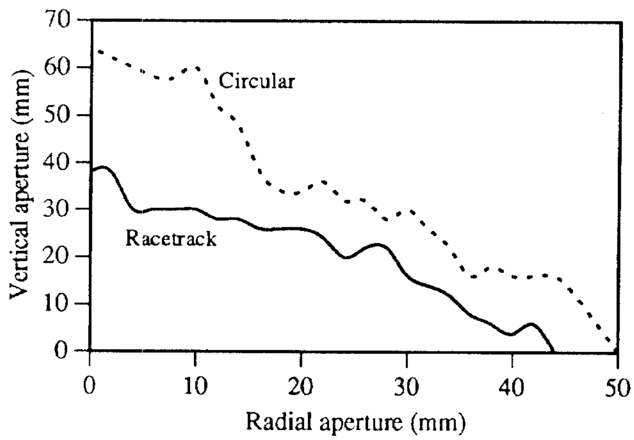

Figure 3. Dynamic Aperture at Centre of Insertion Straight

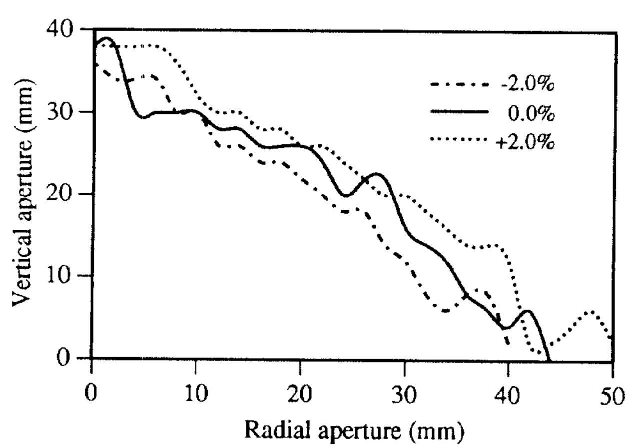

Figure 4. Momentum Dependent Dynamic Aperture

Assessment of potential closed orbit errors in DAPS suggests an amplification factor of about 50, although in practice the effect would be greatly reduced by error correlation when achromats are assembled on a common girder. In any event the effect on DA will be small and the harmonic field errors in the lattice magnets are a more significant

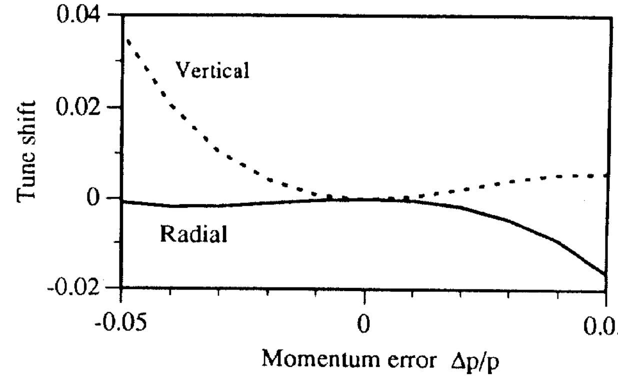

Figure 5. Tune Shift Dependence on Momentum Error

problem. Results in fig. 6 use a set of systematic and random terms in the dipole, quadrupole and sextupole families taken from data at CERN, SLAC and Daresbury [7] and are seen to reduce the DA by a factor 2. This is an illustrative example only, at one working point, and the harmonic errors are very pessimistic, but it serves to demonstrate that further attention is needed to minimise the most important harmonic terms at the specification stage.

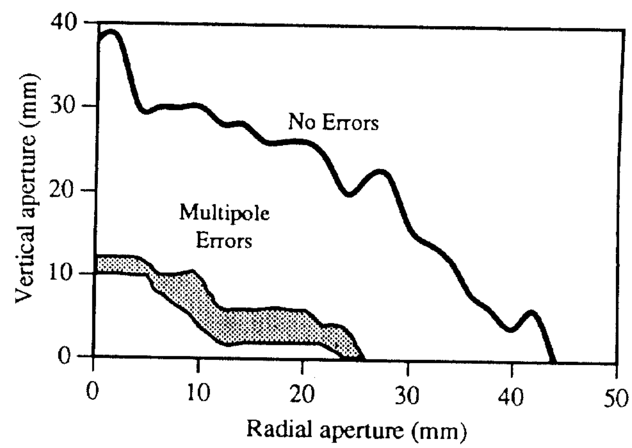

Figure 6. Dynamic Aperture due to Magnet Errors

3. INSERTION DEVICES

DAPS insertion devices (IDs) must cover the range 5-1000 eV with a full complement of up to 6 undulators of 2.5 m and two novel devices in excess of 10 m. Most light sources have relatively high radial beta at the ID straight whereas diffraction limited brilliance demands a value much less than the ID length [8]. DAPS gains a factor 6 in VUV brilliance [1] if Region 2 can be exploited but DA checks reveal reduced lattice performance in this case and results here will concentrate on Region 3. However it is believed that successful Region 2 operation can be achieved in the chosen lattice after further extensive optimisation.

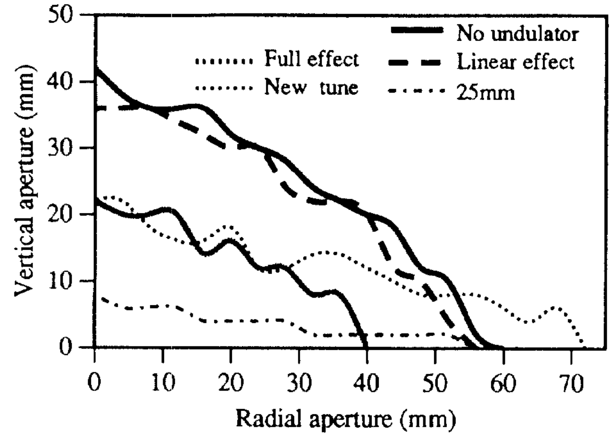

Figure 7. Dynamic Aperture due to Weak Undulator

The linear focussing term of any periodic field insertion will break the ring symmetry and harm the dynamic aperture even if the tune shift is compensated. Additional nonlinear effects arise from harmonic field errors in the undulator, the most important of these being an octupole-like term. DAPS undulators are planned with periods from about 30-90 mm and operating strengths of K = 0.5-3.0 to cover the required photon output range using first and third harmonics [1].Tracking studies using the RACETRACK code have concentrated on 500 MeV behaviour. The main effect of weaker IDs (eg period = 50 mm, K = 1) is through higher harmonics as shown in fig. 7, which also demonstrates the sensitivity to tune values and severe response to a shorter 25 mm device. In practice DAPS needs ID periods below 35 mm only at 1.2 GeV [1]. Figure 8 confirms that the pattern of multiple IDs is not critical so that the full complement can be operated simultaneously, at least at this chosen working point. For the strongest IDs (K=3) the linear effect becomes dominant even when beta beating and phase errors are minimised with the main quadrupole families. However the DA effect seems little worse than for weaker devices : a single ID reduces the stable aperture from 70 mm to 50 mm in the radial plane. A similar result has been found for a possible multipole wiggler with 30 poles and a 1.5 T field.

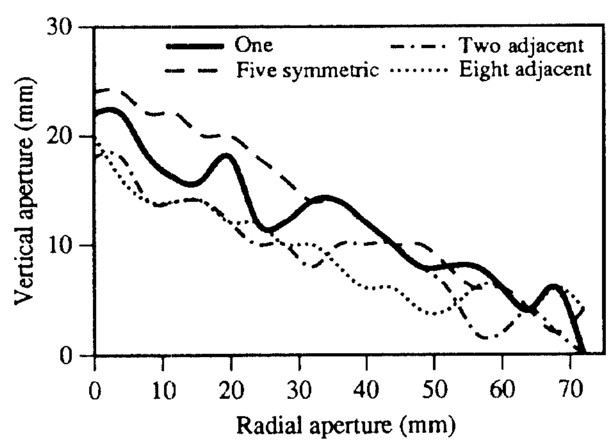

Figure 8. Multiple Undulator Effect on Dynamic Aperture

In conclusion, multiple undulator operation has been demonstrated and DA in excess of beam requirements confirmed in the more conservative high radial beta mode. Results for circular and racetrack geometries are quite similar despite the former having better DA in the absence of IDs.

4. LOW ENERGY PROCESSES

At low energies intrabeam scattering increases the bunch volume and the bunch will also lengthen due to coherent instabilities, with a threshold below 1 mA in DAPS at 500 MeV. These current dependent phenomena are summarised in fig. 9, based on ZAP computations [9], and show a factor 9 increase in bunch length at 200 mA, with an accompanying 70 % emittance growth.

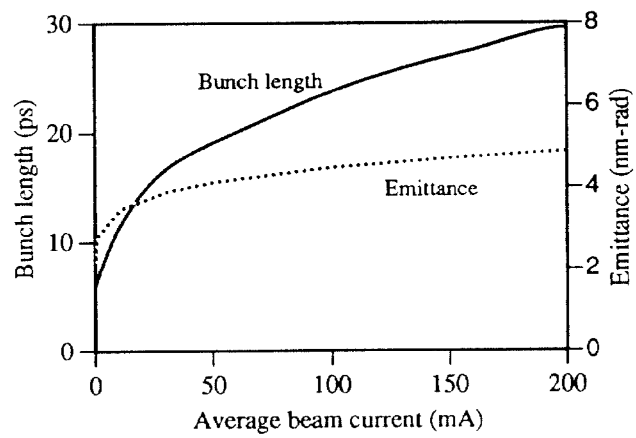

Figure 9. Current Dependent Bunch Length and Emittance

Elastic gas scattering in the vertical plane limits the 500 MeV lifetime to 5-10 hours even with an ID gap no less than 20 mm. Smaller gaps will be desirable at 1.2 GeV and either variable chamber dimensions or in-vacuum magnets may be necessary. Touschek losses are comparable to gas scattering in the radial plane with a realistic physical aperture of ±25-50 mm and the DA should therefore not be less than this. Although this is usually satisfied, Region 2 working points with low ID betas appear to cause lifetime deterioration. All calculations also assume 2-3 % energy acceptance by the RF bucket to minimise longitudinal losses, so that the DA must be maintained in these circumstances.

5. REFERENCES

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