COMMISSIONING AND SUBSEQUENT PERFORMANCE ENHANCEMENTS TO THE HIGH FLUX SYNCHROTRON RADIATION SOURCE HELIOS 2 AT THE SSLS

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Abstract

Helios 2 is a compact, super conducting electron storage ring for synchrotron radiation production with a critical energy of 1.5KeV. Helios was manufactured as a ‘turn key’ light source for research utilising synchrotron radiation with in excess of 20 beam ports for user beam lines. The storage ring was accepted by NUS/SSLS in September 2000 from Oxford Instruments, UK. Performance goals of 300mA at full energy with >10 hour lifetime were readily achieved. Recent work has improved the routinely stored beam current to in excess of 550mA and 6 hour lifetime with 600mA remaining the maximum. Lifetime optimisations have produced further increases in lifetime although so far only 100 A-hours has accumulated for beam cleaning. Short and long-term beam positional measurements indicate a 7 hour measured stability better than 190 microns vertically and 100 microns horizontally with short term variations a factor of 10 better than that without any feed back implemented.

1 INTRODUCTION

Helios is a high flux machine (in excess of 200W per standard beam port) for synchrotron radiation ranging from fractional eV Infra red to 10KeV x-rays with the typical SR output curve. It will serve a diverse research community including numerous industrial research applications within Singapore [1]. While Helios has 700MeV electron energy it should be remembered that because of its small bending radius the critical wavelength / Energy is 0.84 nm/1.5keV. To reproduce these parameters in a conventional synchrotron would require energies of at least 1.1-1.2GeV for a machine of 80-100m circumference, with proportional increases in infrastructure requirements.

1.1 Helios description

HELIOS is a 700 MeV superconducting racetrack synchrotron, consisting of two 180˚ dipoles separated by two straight sections and a circumference of 10.8m. Injection is at 100MeV using a microtron. The dipoles provide a total of 21 user photon ports. The main user ports offer 60mRad horizontally. The first dipole has been modified to allow an infra red port utilising edge effect radiation from Dipole 1.

A fuller description is available in [2]. Helios ‘2’ is the facility at the SSLS, Helios ‘1’ was operated at IBM East Fishkill 1989-98 and has recently been transferred to Jefferson Laboratories USA.

2 COMMISSIONING

Helios 2 was tested to 300mA at the Oxford Instruments premises in the UK in 1999. Installation in Singapore proceeded concurrently with building work for the facility during early 2000. First ‘light’ in Helios was achieved on 31 May 00 with full energy 300mA 8 days later. Beam commissioning to specification was relatively trouble free, with the exception of a persistent difficulty in routine tune measurement. Final acceptance trials completed on September the 30th 2000.

Subsequent operation of Helios 2 commenced shortly after acceptance, primarily for staff training purposes until June 2001 when a more intensive running period commenced to extend some of the operational parameters and commence a more detailed measurement of some basic machine parameters. When the machine was handed over to NUS in September 2000, Helios met all of its beam physics parameters comfortably as described in table 1.

Parameter	HELIOS 2 Design	HELIOS 2 Achieved
Stored current: *at injection* at full energy	>300mA 300mA	350mA
Beam lifetime 1/e	10 hours at 300mA	11 hours at 300mA
Total Divergence rms at λ_c, ports 1-20	<0.70 mrad	0.43mrad
SR Beam size H/V at SLM port	H ≤1.35mm V<1 mm	H=1.35 V=0.76
SR Beam mean ‘skew’	N/S	-15˚

Table 1 Key beam parameters for the acceptance trials of Helios 2 September 00

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3 OPERATIONAL IMPROVEMENTS

3.1 Maximum stored current

In the period of testing June-Aug 2001 substantial improvements to routine maximum stored beam currents were made, primarily by ramping procedure improvements but also by an increased understanding of the accelerator physics parameters, particularly tune. The results for these trials are summarised below in table 2.

Parameter	**Beam current I**	**Beam lifetime *t***
Routine stored current at 700MeV June 2001	580mA	6.5 Hours
Maximum injected current (earlier tests)	960mA	N/A
Peak current at 700MeV (earlier tests)	600mA	5 Hours

Table 2 High current beam trials

For routine stored beam at 580mA the ‘efficiency’ the ratio ‘Stored current at full energy/stored current at injection’ was typically 93%, slightly lower than the more typical 98-100% at 300mA representing losses either at the early or later part of the ramp to 700MeV.

This additional performance approximately doubles the peak flux attainable for an initial small decrease in lifetime. Concerns that operations at higher currents may lead to increased cryogenic losses, (the SR beam exits from a continuous 18mm height slot at 4.6 Kelvin within the outer perimeter of each 180^0 dipole magnet) a very sensitive measure of incorrect SR beam power dissipation, were unfounded as no measurable decrease in excess cryogenic cooling capacity was found i.e. << 1 Watt in a 60 Watt ‘excess’ cooling capacity with a beam current of 580mA.

3.2 Tune measurement

Tune is measured using a tickler excited by a Spectrum Analyser tracking generator and orthogonal tickler strips as pickups. These pickups were later configured to operate as a differential pair through a hybrid and bandwidth limited to 70MHz to allow several stages of amplification before the SA. Even with these modifications, which greatly improve the signal quality and eliminated most of the noise, the tune signal is often elusive, particularly vertically. Work is underway to improve the tune measurement system by modifying the tickler drive, testing the injection kicker as an orbit ‘shaker’ and looking at alternative methods of tune measurement. Plans for automatic tune measurement are on hold until routine measurement is possible.

3.3 Beam positional stability

Operating at a stable beam position will be very important to beam line users although the relatively large beam size and no insertion devices places less of a constraint on beam position than might be required at other facilities.

Conceptually the small size, the cryogenically stable dipole magnet temperatures, the small number of magnets and small vault housing Helios should eliminate many of the more difficult problems of accelerator mechanical stability due to thermal, vibration and mounting stability and leave only those imposed by various subsystems and the electron beam interaction with these.

Measurements have been taken under a number of operational conditions to characterise two aspects, firstly the SR beam position once electrons are ramped to full energy i.e. the initial position and secondly to examine the SR beam position once stored at full energy as a function of duration of a fill to identify hardware or beam physics effects. The initial position varies +/-70 microns vertically from ramp to ramp.

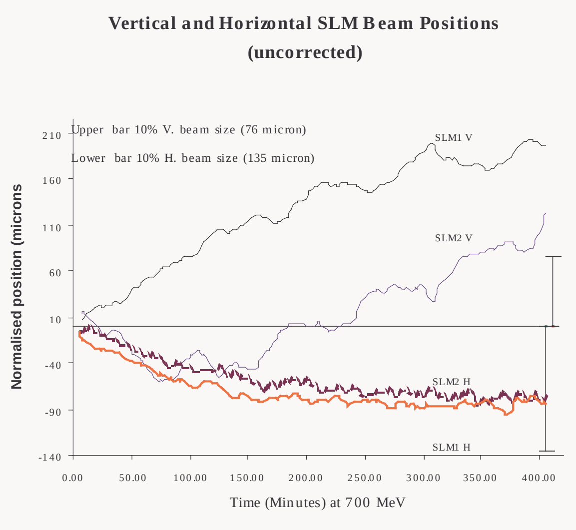

Figure 1 Synchrotron Light Monitor (SLM) beam position from each dipole as function of time for a 300mA fill, averaged.

The data presented in figure 1 represent *uncorrected* motion at the SLMs in each dipole during a fill and are typical. Data has been averaged to take out noise from the image capture process. For vertical motion during a period of full energy beam at 300mA lasting 6.6 hours, the trend is clearly upwards by 190 microns in SLM 1 (dipole 1) and a mean of 100 microns for SLM2 (dipole 2). The cause of the vertical movements is not yet fully understood, while most of the obvious hardware that might cause such a drift has been eliminated such as trim and main magnet currents and possibly Ions and the RF system, we have not yet been able to exclude thermal distortion of the SLM mirrors as a possible effect on the position, although this would not explain the oscillations with a 90 minute period which show correlated movements across SLM 1 and 2 i.e. an increase in SLM 1 V position mirrored by a *decrease* in SLM 2, as lattice behaviour would predict. Improved data to cross check will be available as first beam lines come on line [1].

To correct the deviations measured in figure 1 and those resulting from initial ramp position errors, independent correctors to vertical position are available within each dipole. These so called radial trims allow adjustment of *vertical* beam position within the dipoles and will be used to correct dynamically over periods of tens of seconds, via a short script on the control computer, both for initial position and subsequent deviations. First estimates suggest this would give a maximum deviation better than 30 microns vertically with a relatively simple correction algorithm.

Horizontally position is only controllable by circumference adjustments – changing the rf frequency. This is possible, however the magnitude of the horizontal drift is less than half that of the vertical and flattens out to 10 microns/hour after 3 hours, correcting vertical first is more important.

3.4 Beam lifetime

Helios is unusual for a light source in having 4.5K cold-bore dipoles. There is little doubt this plus the fact the dipole cryostat is open to the beam vacuum space make pumping very effective in a crucial area. This makes achieving a good lifetime at 300mA of > 10 hrs relatively easy to achieve without the necessity to accumulate large A-hours of running. Nevertheless beam cleaning effects are noticeable as absorber surfaces clean up after about 100 A Hours dose on the absorbing surfaces within the dipole. An interesting feature resulting in step improvements can be thermal cycling of the s/c magnet temperatures – deliberately forcing a warm up cycle above 100 Kelvin releases cryo-pumped gas on surfaces, a subsequent cool down then results in an even lower vacuum pressure, a feature first utilised on Helios 1 for lifetime improvements. Helios 1 also exhibited a clear improvement in beam lifetime as a function of accumulated dose for 200mA from 10 to 45 hours with 1200 A-hour operation over a period of 4 years [4], as Helios 2 starts to accumulate comparable A Hours a direct comparison will be made.

4 PERFORMANCE DIFFERENCES

Helios 2 is essentially very similar to Helios 1 in terms of lattice/components. There are two major differences firstly the RF frequency 55MHz in Helios 2 and 500MHz in Helios 1 leading to a large change in the number of bunches from 16 to 2, secondly there is a resultant small circumference difference, an increase to 10.8m in Helios 2 [3] The reasons for the change in RF frequency are complex and do not warrant discussion here but the decision was not made wholly from an accelerator physics perspective. Despite extensive testing it is possible to conclude that there is essentially no difference in machine behaviour in the 0-600mA range from the collective viewpoint of ease of injection, ease of ramping, stored beam lifetime, beam stability and beam size. Additionally no measurable benefit from reducing ‘bunch induced heating’ occurred although detailed component changes from Helios 1 to 2 were more likely responsible for this such as the removal of a protruding ion clearing strip within the main dipole aperture and dimensional changes to Helium volumes close in to the beam aperture of the main dipoles. Some differences in beam properties are present [5][6] but these do not quantifiably affect the ability to operate in this current range. There are however some hardware considerations and despite some elegant design a $\lambda/4$ cavity at 55Mhz in a confined space would not necessarily be an optimum choice. The small cavity gap (20mm) and high voltage gradient make conditioning at extremes of operation (>120kV) difficult. On a machine as small as Helios it is certainly advantageous to use 6” co-axial feed rather than a 500MHz 18” wave-guide and matcher.

It is possible to concur with the conclusions of [6] in that there is no obvious ‘optimum’ RF frequency certainly for lower energy machines and that choices can be made on hardware availability and experience rather than beam dynamics issues.

5 SUMMARY

Installation and operation of Helios 2 at the SSLS has been successfully undertaken. Significant increases to nominal design parameters, particularly high current and increasing lifetime make Helios a machine very suitable for a wide range of SR beam line applications. Future improvements are possible in beam stability and beam lifetime as more machine studies are commenced in the coming operational period, scheduled around beam line installation. A comparison of the operation of two similar low energy machines at two very different RF frequencies concludes little measurable difference in performance over the range 0-600mA.

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