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HELIOS 1-Transportation and Reinstallation at IBM's East Fishkill Facility

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A major advantage of superconducting synchrotron sources is their transportability as an integrated unit and the consequent speed with which they can be brought to full performance at the end site. Conventional systems in contrast must be assembled as individual components with the inevitable inability to preserve vacuum cleanliness and need to fully recommission. This paper summarises the design and pre-testing of Helios at Oxford. Then details are given of the transportation and re-installation and commissioning at IBM's Advanced Lithography Facility in East Fishkill, NY. Most significantly, a stored beam was established in under eight weeks from arrival of the ring on site. Within one month of commissioning the machine was exceeding the performance achieved at Oxford. Finally, brief details of the progress on the construction of HELIOS 2, incorporating a Microtron injector, will be given.

KEYWORDS: X-ray lithography, synchrotron radiation, compact superconducting synchrotron, Helios, commissioning

§1. Introduction

HELIOS, a compact synchrotron X-ray source is currently in the final stages of commissioning in USA. Having been designed as a commercial lithography tool, a key feature is the ability to transport it pre-tested to a manufacturing site.

This paper summarises the pre-testing carried out at Oxford and then describes the shipping and installation at the IBM Advanced Lithography Facility, East Fishkill, USA. Since installation in USA rapid progress has been made in achieving high stored currents at full energy, as described in §5. HELIOS 2, oxford's second X-ray source is under manufacture and progress is described in the final section.

HELIOS has been described previously[1] and details of Oxford testing were described in an update paper at the 1990 Microprocess Conference.[2] For convenience, a few key details are given below.

§2. Design Summary

HELIOS consists of a synchrotron storage ring, including two superconducting magnets, connected to an injection system which consists of a LINAC and transport line. Figure 1 illustrates the storage ring, showing the racetrack design of two dipole magnets and two straight sections, with focussing magnets, RF cavity etc.

As described previously HELIOS is designed to produce at least 8.2 kW of X-ray power. Typical exposure times for lithography are 1 to 15 s from one beam line (HELIOS has 22 beamports).

Table I gives some key operating parameters.

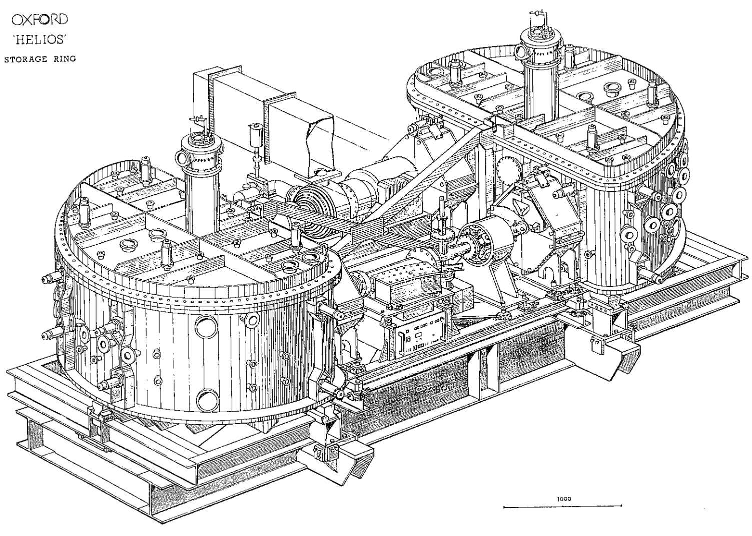

Fig. 1. HELIOS storage ring schematic.

Table I. HELIOS Performance during Oxford Commissioning, 1990.

Parameter		Achieved	vpecification
Stored beam current at Full energy (700 MeV)	:	102 mA	>200 mA
Source size at 700 MeV σr	:	0.36 mm [at 25 mA]	<1.5 mm [200 mA]
Source size at 700 MeV σv	:	0.33 mm [at 25 mA]	<1.1 mm [200 mA]
Lifetime at Full Energy	:	2.2 h [at 70 mA]	>5 h [200 mA]
Lifetime at Full energy	:	>3 h [at 50 mA]	>5 h [200 mA]
Stored beam current at 620 MeV	:	202 mA	—
Maximum stored current at 200 MeV	:	520 mA	>200 mA

Particular features of HELIOS of interest to chip manufacturers are: installation time, reliability, and ease of operation. These features are discussed below, since the machine has now been installed in USA and has been operational (during commissioning) for over a year in UK and USA.

§3. Pre-Testing at Oxford

Commissioning, with electron beam into the storage ring, commenced in May 1991 at Oxford's test facility. Prior to beam commissioning extensive tests of the various sub-systems were carried out. In particular, precise measurements were made of the magnetic field quality of the superconducting dipole magnets. Such measurements confirmed that all key design parameters had been achieved.

By the end of the commissioning period at Oxford all of the component parts of HELIOS had been tested operationally.[3] Also, the machine started approaching its full design performance, as specified in Table I. Figure 2 shows a measurement of the electron beam size, as recorded by a Synchrotron light monitor.

Such results were more than adequate to ensure that full design specifications would be achieved during final commissioning, planned for completion in USA. In addition, the automatic control of HELIOS, via the computer control system, was well established. Intricate operations such as synchronised magnet ramping and automated start-up sequences were a routine part of operation during commissioning.

§4. Shipping and USA Installation

Installation work, especially installing services such as cabling and piping, began in USA in the autumn of 1990, during the final stages of pre-testing at Oxford.

The Oxford commissioning showed that improvements to the vacuum system would be beneficial, since vacuum is crucial in determining beam lifetime—a key operational parameter. Therefore, whilst some subsystems were being shipped and installed to USA the storage ring itself was upgraded at Oxford. Improved vacuum pumping was incorporated; new larger ion pumps and new titanium sublimation pumps. Also, for better diagnostics and servicing more ion gauges and isolation valves for all ion pumps were added. Extensive testing of vacuum sections verified the value of these modifications by achieving base pressures of the order 10^{-10} mbar.

Most of the HELIOS sub systems were shipped to USA by air freight, in relatively standard packing crates.

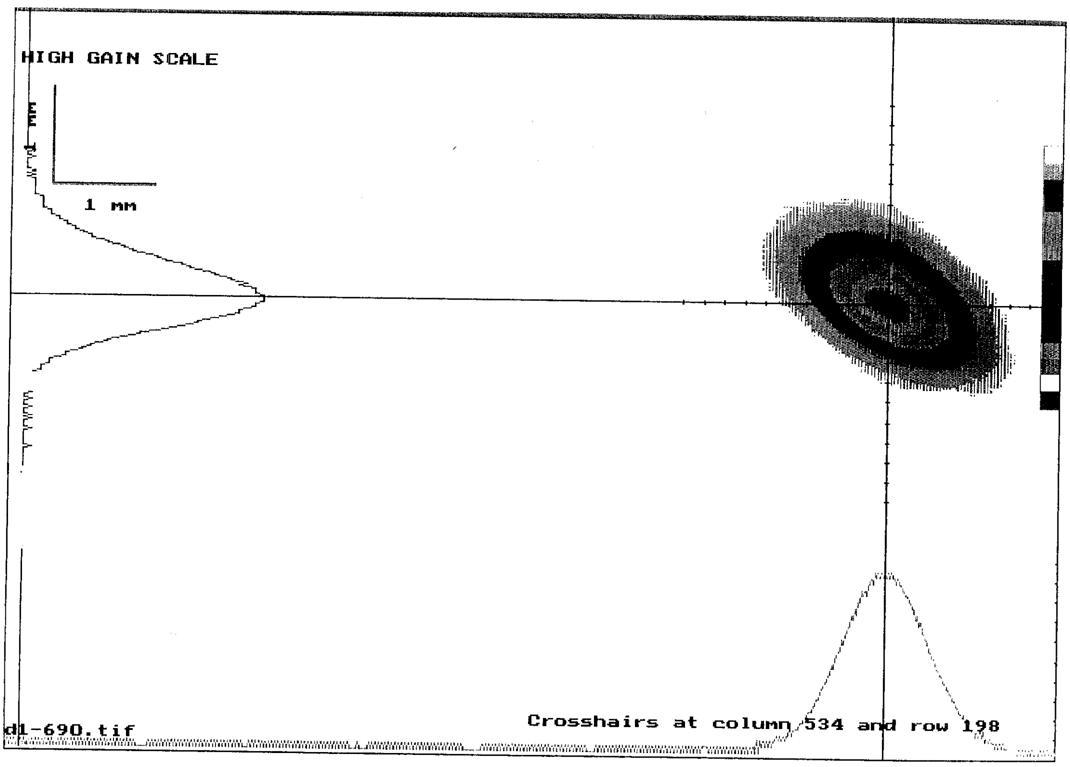

Fig. 2. HELIOS beam image at full energy.

However, the storage ring itself required more specialised transport, being the largest and most sensitive unit. The storage ring was transported from Oxford within a steel support structure. This had built air damping units to provide vibration and shock isolation during its transit by road and sea to New York. The support cradle, with storage ring, was lifted onto an air-ride trailer which was used for the whole journey from Oxford. The top member of the support cradle acted as a lifting beam for the movement of the ring to the trailer.

Storage ring components are mounted onto a rigid stainless steel base. To improve rigidity during shipping additional braces were installed between the two superconducting dipoles and the ring electromagnets.

Figure 3 shows the storage ring, in its support cradle, being unloaded in USA.

The timescales of the shipping and re-installation confirm that HELIOS meets its design objectives of being readily installed at a lithography site. Packing of the storage ring commenced early on 12 March 1991, by midday the whole ring had been moved from its concrete vault and was supported by the transit cradle. The ring left Oxford on 13 March, fully packed in a protective case and secured to the trailer. The ring arrived on site at East Fishkill on 29 March.

USA installation work consisted of moving the ring to its vault, connecting services and transport line, vacuum pumping and bakeout, sub-system testing. This was followed by beam commissioning. A stored beam was achieved on 25 May, within 8 weeks of ring arrival in USA.

Figure 4 illustrates the storage ring installed in at Fishkill. The lithography ports with front end valves and some photon masks are visible in the foreground.

§5. Performance During USA Commissioning

After establishing a stored beam subsequent commissioning has aimed at increasing the stored current, aiming for at least 200 mA at full energy. In addition, routine operational procedures continue to be developed, together with operator training.

Within 1 month of achieving a stored beam in USA, HELIOS had already exceeded its performance in Oxford. A beam current of 120 mA was ramped to full energy on 24 June. Shortly afterwards beam lifetimes of about 3 hours were measured at 150 mA current. Considerably higher lifetimes (~10 hours) have been measured at lower currents and lifetime is continually improving, as expected, due to X-ray beam cleaning.

Figure 5 illustrates a ramp from Injection Energy, resulting in 155 mA beam current at full energy. Note that the ramp duration is much longer than a final operational ramp, since this was a developmental ramp with many pauses. In normal operation it is expected to ramp to full energy in a few minutes. The ramp also show significant beam current loss, since it was not optimised. More recent results have achieved virtually lossless ramps with more than 120 mA beam current.

Automated control software is routinely used to start up and shut down HELIOS, via pre-defined sequences of commands. Ramping the stored beam from injection energy to full energy is similarly automated. Alarm systems report any warnings or failures to operators or to engineers (*e.g.* via a telephone alarm linked to the control computer). A computer link to Oxford from USA facilitates support and software upgrades. Table II lists the machine performance to date (July 91). The lifetime, in particular, is significantly better than in Oxford and is improving (as expected) as X-rays 'clean-up' the vacuum

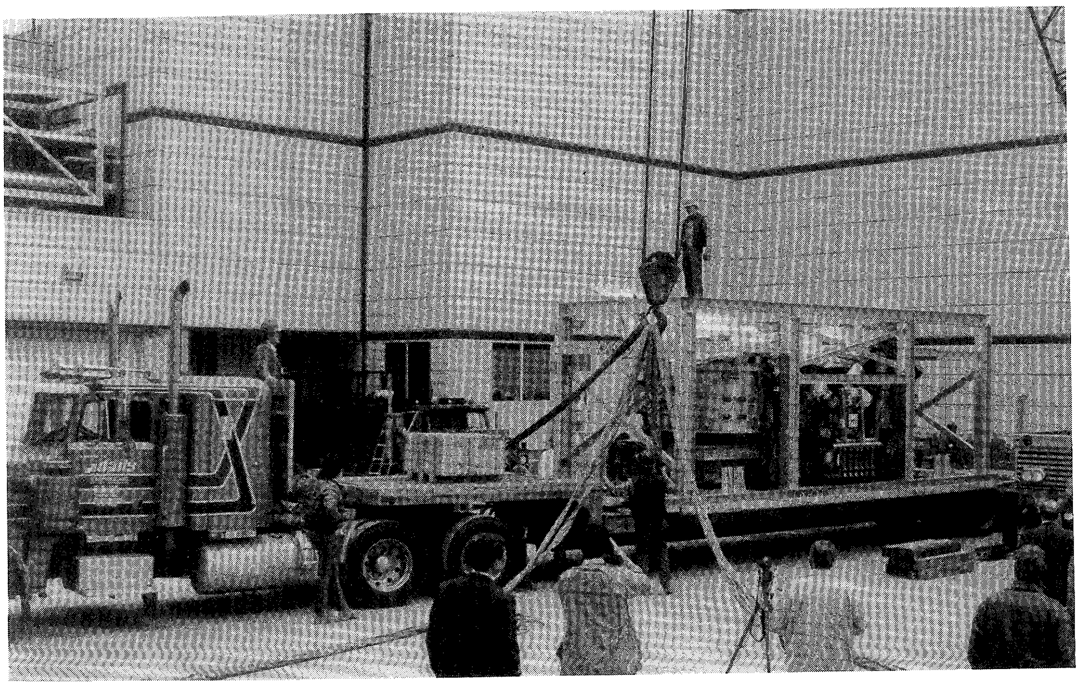

Fig. 3. HELIOS arriving in USA.

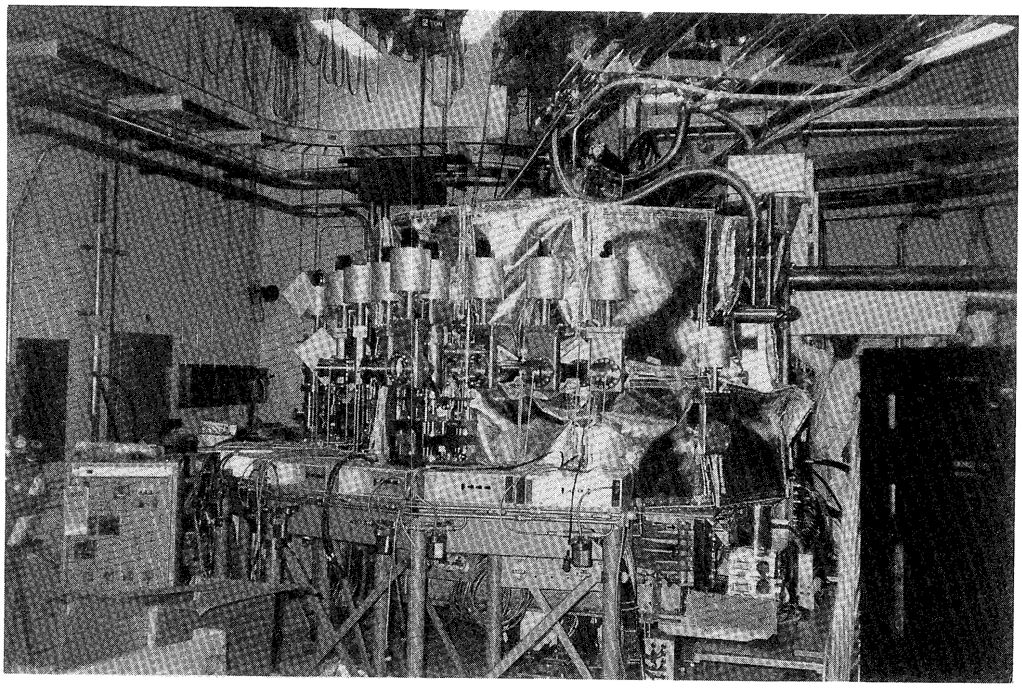

Fig. 4. Helios installed at IBM's advanced lithography facility.

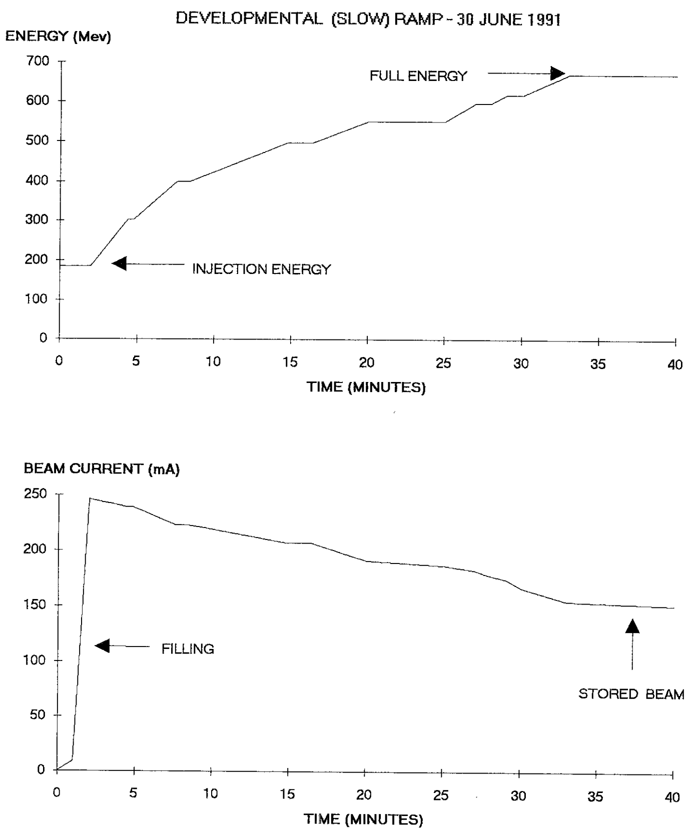

Fig. 5. Ramp to full energy, 155 mA.

surfaces. Vacuum base pressures (without beam) are less than 2×10^{-10} mbar.

Recent results, in injecting over 500 mA to explore the maximums at injection, readily injecting and ramping 303 mA and reaching 240 mA at full energy (i.e in excess of 8.5 kW output X-ray power) suggest that all the operational specifications will be met or exceeded in the next few months of final USA commissioning.

Table II. HELLIOS Performance in USA, 1991.

Parameter	Achieved (July 91)
Max Electron Energy, E_1	670 MeV
Stored electron current at E_1	240 mA (303 mA injected)
Typical source size σr	0.39 mm at 100 mA
Typical source size σv	0.42 mm at 100 mA
Beam lifetime	>5 h at 100 mA
	>4.5 h at 240 mA
Injection Energy, E_0	185 MeV
Stored electron current at E_0	520 mA (max to date)

§6. HELIOS 2

A second HELIOS is currently being manufactured by Oxford Instruments, following the successful performance of HELIOS 1. The design is generally similar, although various improvements (especially to facilitate maintenance and installation) have been made, based on operational experience of over the last 18 months. Injection at 100 MeV will be performed by a 100 MeV Microtron. Extra vacuum valves are included to isolate ring sections. Also, the idea of having pre-assembled sub-sections is being extended by designing completely pre-wired and pre-assembled ring sections to facilitate rapid ring assembly.

The 100 MeV Microtron injector is in an advanced stage of manufacture, for delivery to Oxford in late 1991. The advanced design of the Microtron enables a smaller sized installation than was possible for HELIOS 1. The superconducting dipole magnets are also under construction and are due to start testing in late 1991. Other components are being manufactured in parallel and system assembly will commence in 1992.

Acknowledgements

We are pleased to acknowledge the contribution of the staff of Daresbury and the many Oxford staff who have contributed to the design, assembly and commissioning of HELIOS. We also appreciate IBM's cooperation in installing HELIOS, Figs. 3 and 4, and their contribution to HELIOS commissioning.

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