Technology Transfer on the *Helios* Project

Martin N. Wilson
Oxford Instruments Accelerator Technology Group,
Osney Mead, Oxford, OX2 0DX, UK.

Abstract

Helios is a compact superconducting synchrotron X-ray source for X-ray lithography. It was developed by Oxford Instruments, with substantial design inputs from the Daresbury Laboratory, under the terms of an ongoing contract of collaboration, whereby Oxford pays for man hours provided by Daresbury and also pays a royalty on sales. As a result of this contract, Oxford has been established as a recognised supplier of synchrotron radiation equipment. There have also been benefits for Daresbury.

1. INTRODUCTION

Helios is a compact electron storage ring X-ray source, designed as an industrial machine for X-ray lithography. It uses superconducting bending magnets to achieve a much more compact size and lighter weight than possible with conventional magnets. Its compact size has advantages in a wafer fabrication facility, where the necessity to maintain clean conditions makes space extremely expensive. In addition, because the ring is small enough and light enough to be transported intact, it may be fully commissioned at the vendors factory before delivery to site. Such considerations are important in an industrial machine.

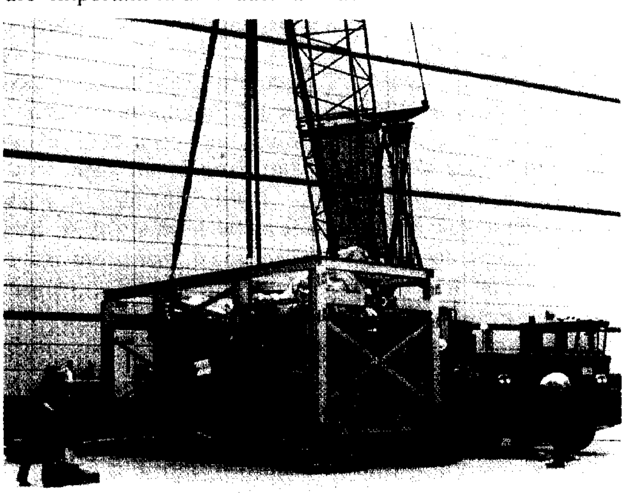

Fig 1: ***Helios 1*** arrives at the IBM East Fishkill site after transportation intact from Oxford.

Helios 1 is now in routine operation for the development of advanced micro-chips at IBM's Advanced Lithography Facility (ALF) at East Fishkill, New York, USA. ***Helios 2***, which contains many improvements and refinements is now in production at Oxford Instruments, for potential use either as an X-ray lithography source, or as a compact source for general research.

Oxford's interest in compact storage rings began in 1983 with a small study contract from BESSY, to investigate the magnet system for a compact weak focusing storage ring, based on the Klein Erna design. This work led to the idea of a racetrack ring, with two 180° superconducting bending magnets. Further design work on 90° superconducting bending magnets was carried out in connection with the KLEAR project of KfK.

In both these activities, Oxford was performing the function of superconducting magnet designer - the Company's traditional strength. It was already clear however that, if these machines were to be a commercial proposition, the manufacturer would need to have the ability to design, manufacture, deliver and maintain the complete X-ray delivery system. For this reason, Oxford set up a technology transfer contract in 1985 with the Daresbury Laboratory of the (then) UK Science and Engineering Research Council. Towards the end of 1985, IBM invited several manufacturers, Oxford included, to submit funded design studies for a lithography ring. As a result of these studies and a competitive bid Oxford was awarded, in Spring 1987, the contract to build ***Helios 1***, which was delivered to the IBM East Fishkill site in Spring 1991.

2. THE CONTRACT

The Oxford Instruments Group comprises a diverse mixture of companies, linked by a common theme: advanced instrumentation for use in research, medicine and industry. Within this Group, it was possible to find all the hardware technologies of a modern accelerator: magnets, vacuum, RF, controls, etc. What was lacking was the basic accelerator physics knowledge, and the experience of actually building and operating an accelerator. The technology transfer contract was therefore formulated to provide expertise from Daresbury across the whole range of accelerator technology, not only the accelerator physics, but also the related technologies, system integration, radiation protection, etc - in fact all aspects of the ring except the superconducting bending magnets and their associated cryogenic system. In addition to the basic design, the contract covered the process of manufacture, installation, commissioning and ongoing support. The terms of the contract, which continues, are that Oxford pays a daily rate for Daresbury staff, plus a royalty on sales in recognition of the intellectual property contributed.

3. THE PROJECT

First task of the project was to settle on the general design concept, and many different lattice configurations were investigated during this phase. With the award of the IBM Study Contract, it became necessary to freeze the design concept for the time being and to work through the design of the whole system in a reasonable level of detail. During this phase, Daresbury staff assumed complete responsibility for the accelerator physics design, providing a detailed optimisation and analysis of all aspects, including the injection process. Designs for the conventional magnets, pulse injection magnets, RF system, controls and diagnostics were all based very closely on existing equipment operating at the Daresbury SRS. With these inputs, it was possible to put together in a rather short space of time, a design which was manifestly practical and capable of working.

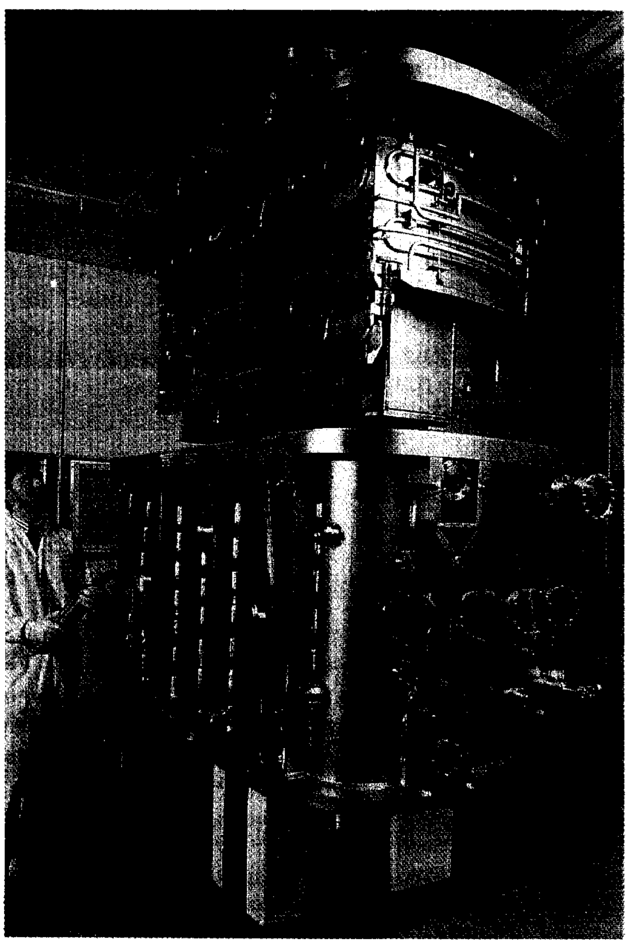

Fig 2: Assembling the superconducting dipole.

Following the award of the IBM contract for building ***Helios 1***, it was necessary to get down to the business of detailed design. Once again, the Daresbury team took responsibility for the accelerator physics aspects, both ring and injection system. Design of the RF system was still based closely on the Daresbury SRS, using the exact cavity shape, with similar tuner, wave guide feed, matcher etc, in conjunction with a commercial TV transmitter. The total current monitor and capacitive BPIs were also based on SRS designs - not only the hardware, but also the electronics. In other areas however the design started to diverge. Pulsed magnets for injection were based on Oxford's own designs using ceramic vessels with the power supplies entrusted to a commercial vendor, Bournlea Instruments. Superconducting magnet development was done entirely by Oxford and the conventional magnets were specified jointly. The vacuum design was done mainly by Oxford. For the control system, it was decided to move away from the SRS system to a suite of software developed at SLAC, for use initially on PEP. A substantial amount of work was done at Oxford to modify this software in line with IBM's specific requirements. Valuable inputs were made by Daresbury on radiation shielding, both the test facility at Oxford and advice to IBM on the layout at East Fishkill. These inputs were particularly helpful to Oxford in negotiating the unfamiliar procedures necessary to become qualified as a radiation site.

In addition to the design process, useful inputs were also made at this stage on the specification of bought-in items, such as the injection linac, conventional magnets, RF transmitter, etc.

During the manufacturing phase, activities at Daresbury reduced markedly, but useful inputs were made on component testing - not only the provision of expertise, but also the loan of specialist equipment. A particularly difficult design problem was the question of wall impedance coupling effects at the transition between the cold bore of the superconducting dipole and the warm beam pipe of the straight sections of the ring. During the design phase, theoretical inputs had been made by the team at DESY, but it was also felt desirable to make some measurements on models - and this was done at Daresbury. Measurements were also made on the RF cavity shunt impedance and all the BPIs were calibrated at Daresbury.

The superconducting bending magnets for ***Helios 1*** contain many innovations. No iron is used in the interests of lightness and minimal field distortion during ramping. It follows that the field quality is determined solely by the accuracy of placement of the superconducting windings. The tight curvature of these coils (banana shaped) makes this accuracy more difficult to achieve than in the more familiar straight dipoles used in high energy rings. Furthermore, it is necessary to leave a substantial gap on the median plane of the outboard coils, to let out the emitted X-rays. These factors, together with the relatively short path length through the magnets, mean that the field can certainly not be considered as hard-edged - it is truly three dimensional. Given this complexity, together with the novelty of the design, it was thought necessary to measure the field quality. The question was, what should the criterion of acceptance be. Our answer was to make tracking studies through the measured field, and look for an acceptable dynamic aperture. In order to do this, it was necessary for Daresbury to make significant improvements and modifications to the ORBIT programme, particularly to take account of the small bending radius (0.5m) which was by no means very large in comparison with the orbit displacements. The resulting tracking runs served to verify that the measured field quality was acceptable and also provided some useful indications of the preferred regions of tune space to begin the commissioning.

During the manufacturing phase, certain diagnostic items were actually built at Daresbury, notably the complete total current monitor, and the electronics for the BPIs. These items were based directly on existing equipment at the SRS, and were technically very good. However, performance was rather less good in the more commercial aspects of response time, delivery time and delivery of complete product, ie including drawings, manuals, etc.

For the commissioning phase, valuable inputs were received at all stages. Firstly the planning, not only working out the detailed technical programme, but also providing useful "nitty gritty" tips on shift organisation, log book keeping, etc. During the initial commissioning process at Oxford, Daresbury staff worked alongside Oxford staff as regular members of the shift crew. Inputs from Daresbury at this stage were absolutely invaluable, particularly in diagnosing faults or unexpected beam behaviour, and then in suggesting the best plan of action. There can be no doubt that, without the input of Daresbury, the initial commissioning time of ***Helios 1*** would have been extended many-fold. Installation and commissioning on site at East Fishkill was handled largely by Oxford staff, although a few visits by key members of the Daresbury team were crucial in illuminating certain problems.

4. BENEFITS TO OXFORD

Without doubt, the first benefit to Oxford was in establishing credibility. At the time of bidding for ***Helios 1***, several storage ring X-ray sources were not performing as well as they might, and potential customers were rightly nervous about the idea of letting a substantial contract to a company which had no track record in the field. Having established its credibility and secured its first order (incidentally at fixed price against fixed specification), Oxford had to deliver! During the conceptual and detailed design phase, undoubtedly the most important input was in the area of accelerator physics. Nevertheless, inputs in other areas:- RF, diagnostics, radiation shielding, etc., were equally valuable. Particularly in the early days, it was extremely helpful to Oxford to be able to access the whole range of theoretical and practical expertise which exists in a large national laboratory. Hardware inputs were also useful, but one has to conclude that a national laboratory is less well attuned to the requirements of delivering, on time, a finished product, complete with manuals, service instructions, drawings, etc. During commissioning, the Daresbury input was absolutely essential, and undoubtedly saved many valuable months at this critical stage of the project.

5. BENEFITS TO DARESBURY

In assessing the pros and cons of technology transfer, it is important not to lose sight of potential benefits for the laboratory which is making the transfer. In the present political climate, it can be extremely valuable for a laboratory which is supported by public funds and devoted almost exclusively to pure research, to be able to point to significant contributions to wealth creation. There are also significant financial benefits - Oxford pays the cost of the staff concerned, and also a substantial royalty on sales. If this income can be used at the discretion of the laboratory management, it can provide a useful freedom to pursue topics which may be outside the official programme. Finally, there may also be some technical benefits. In the present case, the requirement to carry out tracking in a fully three-dimensional field with very small radii of curvature produced significant improvements in the ORBIT programme, and an increased level of understanding of the processes concerned. In addition, concerns from IBM about spot size led to an interesting study and published paper from Daresbury on the general question of emittance versus number of magnets in any ring.

6. CONCLUSION

As a result of this collaboration, Oxford has been established as a credible supplier of accelerator equipment generally. With a 99.5% uptime in 1993, ***Helios 1*** has established itself as one of the world's most reliable storage rings. None of this could have been achieved without Oxford's collaboration with Daresbury, a collaboration which continues to the present day.

7. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the contributions of colleagues at Oxford and collaborators at Daresbury to the success of the Helios project

8. REFERENCES

(1) For a description of ***Helios*** and of X-ray lithography in general, see the special collection of papers in IBM Journal of Research and Development, Vol. 37, No 3, pp 287-474, May 1993.