INDUSTRIAL INVOLVEMENT IN THE CONSTRUCTION OF SYNCHROTRON LIGHT SOURCES

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Abstract

The design, construction and commissioning of a modern third-generation synchrotron light source facility is a major project, costing hundreds of millions of dollars. The delivery of these new facilities, usually on a fixed budget and schedule, requires an effective working relationship with all suppliers providing equipment and services to the project. This paper will examine some of the key issues in developing and maintaining such a relationship with industry during the construction of a third-generation synchrotron light facility. These issues include project planning, the contract specification, the tendering process, communication techniques over the contract term, and other aspects of contract control. Examples, primarily from our experience constructing the Canadian Light Source but also from other new facilities planned or under construction, will be used to examine the effectiveness of various approaches to working with industry.

INTRODUCTION

Over the past ten years there has been a explosion in the demand for synchrotron light research facilities. X-ray radiation from these facilities is being applied to many areas of science and industry (surface science, environmental science, geology, biochemistry, etc.), providing unique capabilities that are not possible through any other techniques. As result, many countries now consider synchrotron light sources as part of their essential national scientific infrastructure, leading to the construction of new facilities and upgrades to older existing facilities worldwide.

In some cases, especially for upgrades, the new construction occurs at an existing national laboratory, where staff has substantial experience with the design, construction and installation of such facilities. Often, substantial systems or sub-systems are designed and assembled in-house with little involvement from industry beyond manufacturing to detailed designs supplied by the laboratories. However, some of the new facilities will be “green field” sites, i.e., are completely new laboratories with little or no existing infrastructure. A project to construct a completely new facility adds many additional demands and challenges on the project team, some of which can be met with broader involvement from industry in all phases of the design, construction and operation.

This paper looks at involvement of industry in the Canadian Light Source Project, especially for the accelerator systems, and examines some of the issues and challenges that arose, and how we managed them.

CANADIAN LIGHT SOURCE PROJECT

The Canadian Light Source (CLS), shown in Figure 1, is a new, third-generation, 2.9 GeV synchrotron radiation facility located on the University of Saskatchewan campus. The facility uses an existing 250 MeV electron linac to inject into a full-energy booster synchrotron. In turn, the booster fills a compact 12-cell storage ring, which has a circumference of 171 m. Technical details of the facility are described in reference [1].

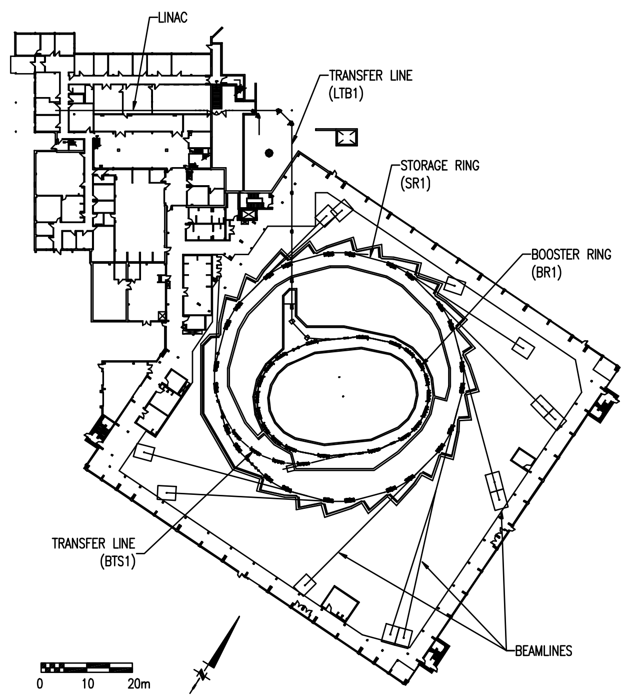

Figure 1: Layout of the Canadian Light Source facility

The University of Saskatchewan received approval to proceed with construction of the facility, including at least six beamlines, in 1999 March, with a budget of $141 million Canadian dollars, including all equipment, civil construction, salaries and overhead. When the project was approved, the core technical team consisted of less than 20 people from the Saskatchewan Accelerator Laboratory, including two accelerator physicists, one mechanical engineer, one electrical engineer and a four-person group in computer controls and instrumentation. The challenge for the team and the University was to complete the facility within five years of the approval date. It was clear that, even with a planned expansion of internal staff to more than 60 people, much detailed design work and construction would have to be done by external companies.

The key challenge was to determine what should be done internally by CLS staff, and what should be contracted out to industry. Other new facilities face the same challenge, although the response will depend upon different circumstances.

CLS EXPERIENCE

This section presents a review of CLS experience with many of the major industrial contracts issued during the project. Essentially all contracts over $1 million Canadian, except those for building construction, are discussed.

In our general contracting strategy we distinguished between the accelerator construction and the experimental beamlines. Since we only planned to build one accelerator, we sought to reduce the design effort within CLS by contracting out the detailed design and fabrication of as many subsystems as possible. Only the control, machine protection, and personnel protection systems were designed in-house. Consistency of these systems across the entire facility was very important for long-term maintenance and development, and this could only be achieved by having strong internal design control. For the beamlines and insertion devices, we decided that some in-house design capability was important for the long-term development of CLS so we took a more diversified approach to delivering the beamlines.

Project Services

These services include the two most important contracts for the success of the CLS Project: the technical services provided by CLS Inc. staff; and the construction and project management services provided by UMA Management Services.

At the start of the project, all staff members with the previous Saskatchewan Accelerator Laboratory were transferred into a new non-profit corporation, Canadian Light Source Inc., which had primary responsibility for the technical design, construction and operation of the CLS facility. As a separate corporation, CLS Inc. has the legal and organizational freedom to establish policies and procedures most suitable for this responsibility. In particular, this includes control over the designs and other intellectual property developed during the project. This allows CLS freedom to decide how to manage this property to support the development of the facility and its scientific research program.

The contract to engage UMA, an experienced external engineering firm with extensive experience managing large technical and civil construction projects, was also vital to the success of the CLS Project. UMA had the responsibility to manage the project, including control over the budget, all contract tendering and negotiations, contract management, supervision of on-site contractors, as well as design and engineering support for CLS staff. In general, UMA always had two to three staff on site, with additional design and engineering staff added whenever necessary.

These two contracts resulted in a project delivery team that had both strong project and contract management skills (UMA) based on many decades of experience in industry, as well as strong accelerator design capability (CLS). Key to the success of the team was effective integration of the skills from both companies during all phases of the project. This allowed CLS staff to become more experienced in many essential skills for managing smaller future projects and contracts, while allowing UMA staff to become more aware of the unique characteristics of accelerator construction projects.

IT Network and Services

Early in the project, we decided to use a single redundant computer network for all data and communication services, using virtual LANs to separate office, control and beamline networks, and implementing voice-over-IP for telephones. However, we did not have the expertise to perform the analysis or do the design, necessitating a contract with an experienced Information Technology (IT) consulting firm. There were two major components to this IT contract, awarded to EDS Canada Ltd.: design and installation of the core computer network services for the entire facility, and the development of a set of guidelines and recommendations (called the IT Architecture) for the future development of IT services. To ensure that the network would provide sufficient expansion capability to meet likely future needs, EDS conducted an analysis of all likely CLS IT requirements, including visits to other facilities and extensive interviews with CLS staff and potential users.

Managing this contract posed several challenges for us. While the specification for the core hardware infrastructure was reasonably clear, the analysis phase, while necessary, was both vague and poorly defined. This situation led the University to establish an oversight committee to monitor the progress on the contract. Committee membership included nationally recognized experts in high capacity data networks, large-scale scientific computing and an IT expert from an international light source facility. The committee members were extremely helpful and their input helped ensure the contract scope was completed within budget.

Booster Synchrotron

The entire booster synchrotron was the first technical procurement contract of the entire CLS Project. Only the basic accelerator lattice and the general design guidelines were specified in the Request for Proposal. The decision to make the first procurement a single "turn-key" package allowed us to assess, and hence reduce, the overall risk to the entire project. This approach forced the team to develop the general guidelines early, rather than getting into detailed design too quickly. It also allowed an early check on our accelerator cost estimates, since the storage ring costs were estimated the same way as the booster costs. By contracting out all the detailed design of the booster, we could then focus on the main storage ring, which was far more important to the final performance of the facility.

The booster contract was awarded to Danfysik in 2000 January, beam commissioning started in 2002 July, and the booster was accepted by CLS in 2002 September after it met all the required performance specifications. Earlier, Danfysik had constructed the booster synchrotron for ANKA and, more recently, they have also been award the contract for the construction of the injector for the Australian Light Source Project.

For the project team, this contract met all of the planned objectives. The cost confirmed the basis for the storage ring budget, the CLS engineering team focused on the design of the storage ring, and many integration issues for control, diagnostics, and instrumentation were addressed before being finalized for the storage ring. The commissioning work also provided valuable experience to the accelerator physics team, with sufficient time to incorporate this experience into plans for the storage ring commissioning.

Storage Ring RF System

Shortly after the CLS project was approved, Hasan Padamsee of Cornell suggested that CLS consider using superconducting RF (SRF) for the main storage ring, noting that SRF was now being used reliably in several large particle physics facilities. The team conducted an urgent investigation into the relative merits, including costs, of normal versus superconducting RF, and decided to use SRF. There appeared to be relatively little difference in cost and, since Cornell had transferred their cavity design to industry (ACCEL), there were commercial sources available for all the key components. In addition, there was also good technical and maintenance support available, allowing the project team to keep the operating staff demands small.

The entire RF system was awarded in three contracts to: ACCEL Instruments GmbH for the superconducting cavity, cold valve box, and instrumentation; Thales Broadcast & Multimedia AG for the 300 kW, 500 MHz RF amplifier system; and Linde Kryotechnik AG for the TCF-50 liquid helium cryoplant. The cavities are essentially the same as those supplied by ACCEL for Cornell, NSRRC (Taiwan) and, in the future, for DIAMOND. The RF amplifier is a slightly upgraded version of that supplied by Thales to both SLS and Daresbury. Finally, the cryoplant is a standard design that Linde has sold throughout the world. In all cases, the suppliers provided training to CLS technical staff to perform routine maintenance. Significant technical changes are performed through a supplementary contract. The only portions of the RF system that was not in the scope of these contracts were the waveguide to the cavity and the low-level RF control system.

The overall system has performed exceptionally well, allowing CLS to be the first synchrotron light source to use superconducting RF for the main RF system. At the same time, the system is maintained by only two technical staff as part of their general responsibilities for RF and cooling systems.

Storage Ring Vacuum System

There were two major contracts awarded for the vacuum system: pumps and controllers by Varian, and the vacuum chambers by FMB GmbH.

CLS wanted to reduce the diversity of pumps and controllers within the facility to ease the maintenance burden and the control system integration effort. Hence, a single contract was awarded for all standard pumps and controllers in the facility, including the booster, storage ring and beamlines. In turn, CLS supplied the pumps to other contractors as required. Generally this approach worked well, except for the additional customs paper-work.

FMB had previously manufactured the vacuum chambers for both BESSY II and SLS, and so the CLS chamber manufacture went smoothly. However, some dust contamination occurred during the final cleaning steps, and most chambers had to be returned to FMB for additional cleaning. Final assembly, vacuum bake-out of each cell, and installation at CLS proceeded without any additional difficulty.

Storage Ring Magnets and Power Supplies

We broke the tendering for the storage ring magnets into two separate packages: the 24 dipole magnets, and all the quadrupole and sextupole magnets. The contracts also required the vendors to measure the field characteristics of each magnet to confirm that the properties met the specification before shipping them to CLS. Although we planned to develop a magnet measurement facility for insertion device development, it would neither be ready in time nor were staff available to measure all these magnets in-house.

The dipole magnet contract was awarded to Telsa Engineering Ltd., who had also manufactured the dipole magnets for ANKA. Sigma-Phi S.A. was awarded the contract to supply the smaller quadrupole and sextupole magnets. All magnets met or exceeded CLS technical requirements [3].

Once the magnets were specified, and the electrical characteristics were known from the detailed designs, the power supplies could be specified. All magnet power supplies were tendered as a single contract, to ensure a consistent control system interface to all supplies. This contract was awarded to IE Power Inc., who also supplied similar power supplies for the SPEAR III upgrade. After a couple months to fine-tune the feed-back loops, all power supplies have achieved the desired stability and are working reliably.

Beamlines and Insertion Devices

As mentioned earlier, we used a more diversified approach for the design and construction of the beamlines. The initial seven research beamlines for the facility are:

- a Spherical Grating Monochromator for soft x-rays, which was moved to CLS from the SRC facility in Madison, with some modifications and upgrades (by McPherson Inc. and Oxford-Danfysik Ltd.) to accommodate the higher beam power at CLS;
- a vacuum ultraviolet line, using a Variable Line-Spacing Plane Grating Monochromator, designed and fabricated by Jobin-Yvon Ltd.;
- a soft x-ray Spectro-Microscopy beamline, based on the design of the Molecular and Environmental Science beamline at ALS, in which the detailed design was done by Full Spectrum Design Group (Saskatoon) working closely with CLS, and the components were manufactured by Johnsen Ultravac Ltd.;
- a protein crystallography beamline, designed and built by ACCEL;
- a hard x-ray materials science beamline, designed and built by Instrument Design Technologies Ltd.; and
- two infra-red beamlines with spectrometers by Bruker and the optical chicane designed and manufactured by Advanced Design Consulting Inc.

All front ends were based on APS designs, modified extensively by CLS and fabricated by Johnsen Ultravac. All five x-ray beamlines use insertion devices. Four of these, two planar pure permanent magnet undulators, one pure permanent magnet elliptically polarizing undulator, and one hybrid small-gap in-vacuum undulator are designed, assembled and tested in-house with the support structures contracted out to Advanced Design Consulting for the out-of-vacuum undulators, and to RMP s.r.l. for the in-vacuum device. A fifth insertion device, a superconducting multipole wiggler, was contracted to Budker Institute of Nuclear Physics which has delivered several similar wigglers to BESSY II and Elettra.

ISSUES AND CHALLENGES

As with many other major projects, there were a variety of issues and challenges that arose when so much work is done by outside contractors. The standard project management context (the balance between scope, cost and schedule) is, perhaps, the best way to review some of the key issues.

Scope

It is exceedingly important to have an early clear vision of what design, work and systems will be the responsibility of the laboratory and what will be contracted out, if possible. Consequently, we decided that, for the accelerator systems, CLS would be responsible for the overall lattice design, most of the control system, and most of the installation. The lattice design affects the fundamental performance of the facility, and has to be under the control of the laboratory. It is important that, despite the diversity of equipment in the facility, the operator should be presented with a consistent interface for control. This interface will probably evolve considerably over the life of the facility, and so CLS should have complete responsibility for the control system. Finally, since CLS staff would ultimately be doing most of the routine facility maintenance, having primary responsibility for equipment installation allows the staff to become familiar with all the systems.

As mentioned earlier, the strategy for the beamlines was different. We attempted to get as broad a range of experience as possible in the detailed design of beamlines. In all cases, a reasonably detailed conceptual design was developed and reviewed. A technical specification was then assembled for tendering, using the conceptual design as a basis. Vendors could propose changes to the design, so long as the basic specifications were still achieved.

A key element in specifying the scope is a set of general guidelines and standards for various interfaces, e.g., naming conventions, drawing standards, electrical guidelines, control system options, standard suppliers and vendors for key parts, etc. In a mature laboratory, these have usually evolved over a period of time, but the establishment of these guidelines for a new facility is a large amount of work, often done by new or inexperienced staff. If these are not in place, then much additional effort is needed either to specify these on a contract by contract basis, or to cope with the diversity of equipment interfaces upon delivery.

When determining the scope of a specific tender package, the number of likely bidders should be considered. Usually three or more vendors are desirable to ensure a good range of competitive bids. Naturally, there has to be some balance between the effort to manage and integrate several smaller packages, and the potential increased costs from less competitive bids.

Cost

The most effective cost containment strategy is to ensure a competitive tendering process exists that allows the largest number of eligible vendors to bid. When we had three or more bids, the maximum price was typically two or more times the minimum price. Consequently, tendering practices that restrict technically capable vendors will often result in increased costs. All CLS tenders were posted on the University of Saskatchewan website, with a link to the CLS website.

Management of the costs for contracts to supply equipment is usually simple. More challenging is constraining cost increases when a substantial amount of custom engineering is required as part of the contract. Then the main challenge is to control the scope changes. Scope changes after a contract has started usually increase the costs and, quite possibly, the schedule as well. These changes often arise from incomplete, or evolving, designs for other parts of the system or facility. Thus, it is important to have a formal engineering change control process as early as possible in the project. Project staff members, who have often never been concerned with the consequences of "small" changes, need to realize how many drawings, documents and contracts can be affected by relatively small changes.

Schedule

Schedule slippage is the biggest challenge a project team usually faces on a large construction project like CLS. It can result in frequent changes to plans for subsequent activities, so that the possibility of delays should be considered as part of the overall risk management for the project. For example, of ten major contracts for CLS accelerator subsystems, completion of eight of them was delayed by five to eight months from the original contract dates. Thus, assume that significant delays are possible in almost any contract and adjust the overall plan accordingly. For CLS, we worked hard to ensure that delivery dates for all storage ring systems was at least one year before our planned commissioning completion.

While delays seem to occur frequently on contracts, some of the delay was the result of either design changes that we requested, or delays in responding to requests for additional information or equipment. On average, it is likely that we (CLS) were responsible for between one quarter and one third of the delay. Often we found it very challenging to ensure that our staff responded to supplier information requests in a timely manner.

One approach that we used to address possible contract delays on a couple of time critical contracts was to negotiate a bonus-penalty clause. (Canadian law generally requires a bonus clause in a contract if a penalty clause is used, imposing some symmetry on the contract.) In one case, the contract was completed on the day that maximized the bonus; in the other case, the contract was completed 40 days late but CLS accepted responsibility for 24 days of the delay. While imperfect, both CLS and the vendor paid much more attention to possible contract delays.

Communications

The importance of effective communication with contractors should never be underestimated. During all phases of tendering, monitoring, or closing out a contract we use a standard form that lists each issue raised, progress towards resolution, and when the issue is resolved. This form is then used maintain a record of most on-going discussions with contractors over each contract phase. In general, we usually plan for about three to five face-to-face meetings for each contract, as well as ongoing progress reports. In some cases, weekly teleconferences with the electronic exchange of the issue resolution form have been very effective for ensuring that information is exchanged when it is needed.

One of our challenges was to ensure that CLS staff members were aware and capable of responding to contractor requests as needed. Too often the response to a contractor's request for information (usually sent by email) was delayed because the person who received it was either away or could not respond. This was one challenge that we are still trying to resolve without too much overhead effort on all communications.

CONCLUSION

The schedule slippage in the various contracts for the storage ring delayed the completion of storage ring installation until late summer of 2003. We started storage ring commissioning in the fall of 2003 and, by 2004 May, we completed storage ring commissioning. We met all essential performance specifications [4] five months behind schedule, but still within budget. We expect to receive authorization to start routine operations from the Canadian Nuclear Safety Commission in 2004 July, and to begin general user operations in 2005 January.

ACKNOWLEDGEMENTS

The success of the CLS Project is the direct result of strong commitment and dedication of all the CLS staff, UMA project staff, University of Saskatchewan staff and senior management, and project contractors. I would like to express my gratitude for their immense effort to ensure the excellence of the new CLS facility.

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