Design, Construction, and Procurement Methodology of Magnets for the 7-GeV Advanced Photon Source*

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Abstract

All major magnets of the Advanced Photon Source (APS) have now been measured and installed in the facility. This paper describes the mechanical design, construction, procurement philosophy and methodology, and lessons learned from the construction and procurement of more than 1500 magnets for the APS storage ring, injector synchrotron ring, and positron accumulator ring.

I. INTRODUCTION

The Advanced Photon Source (APS) is located in the southwest corner of the Argonne National Laboratory (ANL) approximately 35 miles southwest of Chicago, IL USA. Ground was broken for the 79-acre site on June 4, 1990. APS, the world's most brilliant x-ray source, is scheduled for operation in the fall of 1996. A plan view of the site is shown in Fig. 1. The storage ring has a circumference of 1104 m (3640 ft) and contains 1128 magnets which direct and focus 7.0-GeV positrons in their vacuum environment of 10^{-10} Torr. The injector synchrotron contains 302 magnets, and the positron accumulator ring (PAR). which produces a single circulating bunch for injection, contains 36 magnets. With the addition of the low and high energy transport (LET and HET) lines, the total number of magnets is 1514 (excluding the linac system). This paper will discuss the methodology used to design, construct, and procure these magnets.

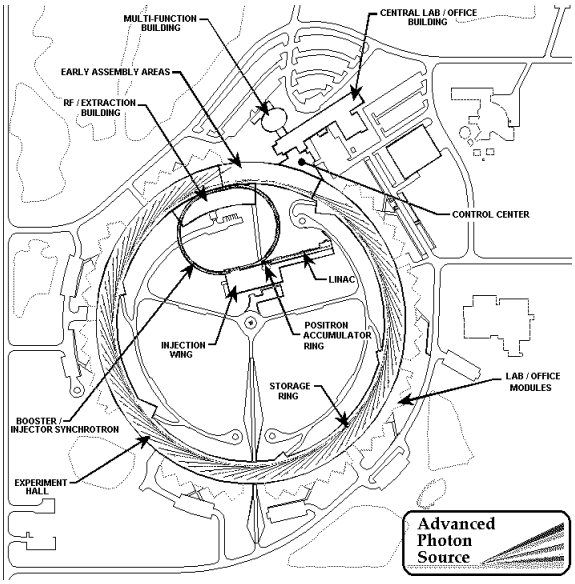

Fig. 1: APS Site Plan View

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† Magnet Group Leader during the course of this work.

II. MAGNET DESIGN AND CONSTRUCTION PROCEDURE

The task of fabricating 1514 APS magnets of 19 different types was accomplished by the following 7-step process:

1. Conceptual Phase - Title 1 Process
2. Prototype Phase - Title 2 Process
3. Prototype Phase
4. Construction Phase
5. Tooling Design and Fabrication
6. Travelers and Inspection Forms
7. Final Inspection/Shipment

In the Conceptual Phase, the physics design is reduced to a conceptual design in terms of magnet mechanical parameters, pole profiles, coil packaging, and construction materials. The resulting conceptual design is then reviewed by internal and external peer reviews. Only after acceptance by all reviewers is the design committed to Title 2.

In the Prototype Phase - Title 2 Process prototype drawings are prepared using computer-aided design (CAD) techniques. These drawings are again reviewed by internal and external peer reviews including the originating physics design team. After passing these reviews, the design is committed to prototype construction.

The prototype is built and tested in the Prototype Phase. In construction of the prototype, basic traveler documents are created outlining construction details and process measurements during fabrication. These travelers, which each magnet has during its construction and operational lifetimes, also use standard QA/QC methods. Again, the prototype and its performances are reviewed internally and externally. Only after passing these requirements are final construction drawings prepared.

In the Construction Phase, specifications, statements of work, and work packages are prepared to procure steel, copper, laminations, parts, and complete magnets from industry. At this point a strong relationship is essential between engineering staff and procurement specialists. Basically, four processes were used to fabricate the required magnets.

- Procure parts from industry and assemble magnets in-house at ANL and by industry. This method was used to fabricate storage ring quadrupoles, sextupoles, and corrector magnets.
- Procure parts from industry, fabricate some in-house, and assemble magnets at ANL. This method was used to fabricate synchrotron dipole, quadrupole, sextupole, and corrector magnets, and the PAR corrector magnets.
- Procure complete magnets from industry from specifications supplied by APS physics personnel. Several magnet

types were purchased complete: storage ring dipoles and correctors, PAR dipoles and PAR quadrupoles, LET dipoles and quadrupoles, and HET dipoles and quadrupoles. These complete magnets were manufactured both in the U.S. and abroad.

- Pulsed magnets, not considered in this paper, were built completely in-house and are primarily considered prototypes.

The tooling used in the construction phase was designed by APS and used to fabricate prototypes. Only then is it "certified" for construction use and sent to vendors. Travelers and inspection forms are created jointly by engineering and QA/QC personnel. When the magnet is completed, tested and inspected again, all paper work is reviewed before shipment to the APS site for installation.

III. PRODUCTION MAGNETS AND RESULTS

Magnet profiles for the synchrotron dipole, quadrupole, sextupole, and corrector magnets are shown in Fig. 2. Magnetic measurements have been reported [1] and [2] and show that, e.g., for the synchrotron dipole, the integrated field shape is flat to within 2.5×10^{-4} in the required field region. Multiple coefficients of the quadrupoles and sextupoles satisfy required field specifications. Magnet profiles for the storage ring are shown in Fig. 3. Results for the quadrupole magnets have been published [3] and [4] and meet or exceed tolerance requirements. Results for the other storage ring magnets will be reported in these proceedings. The major groups of magnets procured solely from outside vendors are the storage ring dipole and corrector magnets and the PAR dipole and quadrupole magnets. The latter two are shown in profile in Fig. 4. All magnets were measured in the APS Magnet Measurement Facility [5].

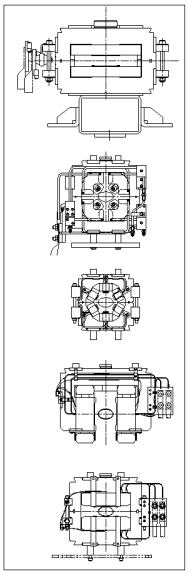

Fig. 2

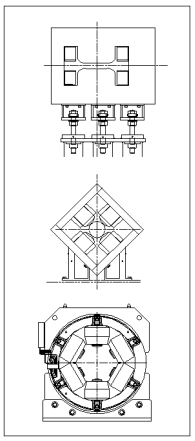

Fig. 4

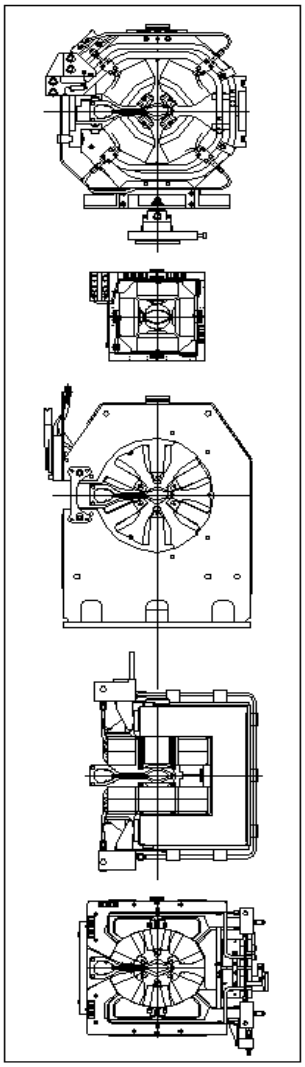

Fig. 3

IV. PROCUREMENT STRATEGY

Three predominant strategies surface when one scrutinizes the acquisition process for the large number of magnets installed in the APS. The strategies which were strongly supported by APS management can be summarized as follows:

1. Establish and maintain throughout the course of the procurement cycle a strong partnership between the APS procurement specialist and the magnet design engineer. To this end, a procurement specialist was assigned to process all of the major and/or critical purchases emanating from the Magnet Group. Front-end involvement in tasks such as the preparation of statements of work, identification of potential bidders, and the assessment of vendor qualifications was a shared responsibility. Ownership for the success of the acquisition process further enhanced and strengthened the linkage and teamwork between procurement and engineering.
2. Maintain direct control over the procurement of the essential raw materials utilized by subcontractors in fabricating major magnet subassemblies such as coils and cores. The quality of the magnet steel, the copper conductor tubing and the laminations were designated at the outset as critical applications, requiring the Laboratory's direct control in specifying, purchasing, and inspecting. These items for all of the synchrotron and storage ring magnets became Laboratory-furnished material for subcontractors contracted to fabricate cores and coils.
3. Commit to providing APS resources, specifically technical expertise, to accelerate learning and diminish start-up anxieties for vendors fabricating key magnet components. This effort consisted of two basic elements. First was the supply of critical tooling and prototype units developed at the Laboratory. For example, Procurement coordinated the shipment of core stacking fixtures utilized in prototype development, for use by the vendor in setting up production. Also, sample cores fabricated by the Laboratory were sent to a number of vendors for their use in checking dimensional requirements as well as form and fit. Secondly, the Laboratory was adamant about dispatching skilled, senior-level magnet technicians to work with our vendors' production personnel at the outset of the contract term, to develop the assembly/fabricating skills learned at

the Laboratory during prototype development. This training was invaluable in assuring a successful first-article review.

V. PROCUREMENT METHODOLOGY

The typical major magnet procurement ($500,000 and above) generally followed the sequence described below. The reasons for the successful completion of these procurements are (1) the clear-cut contract authority and responsibility assigned to the procurement specialist and magnet engineer and (2) the continuing communications between the engineer and specialist throughout the term of the contract.

The sequence of events from planning to contract closeout were as follows:

1. Advance Procurement Plan—Laboratory policy dictates that a procurement plan be written which addresses the critical issues concerning major procurements. Areas such as “make or buy”; potential sources of supply; the need for dual sourcing; risks associated with technical, cost, and delivery factors; schedule and budget constraints; and QA matters such as reliability and first-article requirements were all discussed and documented. The Plan became the first opportunity to bring the purchasing representative together with the engineer and acted as the first building block in cementing a strong interdepartmental relationship.
2. Bid List Formation—Cooperation was enhanced because of the dual responsibility for formation and approval of the bidders list. Although recognizing magnet engineering's expertise and pre-eminence in this area, Procurement was allowed to augment the bidders listing to assure compliance with socio-economic requirements mandated by DOE. An important point to make is that a significant number of prospective bidders were known entities as a result of pre-bid vendor visits and market surveys.
3. Contract Review—Prior to issuance of the completed contract, an internal review was conducted to insure that the cognizant engineer was knowledgeable concerning his/her duties and obligations. Sometimes if the value and complexity of the contract warranted it, the vendor was brought into the picture in a face-to-face meeting to make certain that all the parties understood those contracted obligations
4. Contract Administration—It was clear and unequivocable that Procurement would act as the clearinghouse and focal point for data dissemination in order to assure contract compliance. It was also clear that direct dialog between the magnet engineer and the vendor concerning technical matters was encouraged. Having already formed a strong link with Procurement, it became very easy for the engineer to recognize when a problem warranted Procurement intervention and resolution.
5. Contract Closeout—As a shared responsibility the magnet engineer and procurement specialist assured that the vendor was diligent in supplying inspection data sheets, that there was proper disposition of rejected items, that payments would be made upon receipt of goods (signatures of both parties required on all invoices), and that surplus Laboratory-furnished material and all loaned tooling was properly returned.

In retrospect, the strategies and methodology employed to procure magnets for the APS proved to be quite reliable and served to bring two somewhat divergent groups (procurement and engineering) together as a team, focused solely on assuring the successful installation of the APS.

VI. CONCLUSION

Due to the efforts of many people, the APS facility is nearing completion. All major magnets have been fabricated, tested, and installed in the facility. Magnet performance has been reported in the literature, and facility commissioning is now proceeding.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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