EVOLUTION OF THE DESIGN OF THE MAGNET STRUCTURE FOR THE APS PLANAR SUPERCONDUCTING UNDULATORS*

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Abstract

A number of superconducting planar undulators (SCU) with different pole gaps and periods were designed, manufactured, and successfully operated at the Advanced Photon Source (APS) storage ring. A key component of the project is the precision machining of the magnet structure and the precision of the coil winding. The design of the magnet core had a number of modifications during the evolution of the design in order to achieve the best magnetic performance. The current design of the magnet structure is based on the assembled jaws with individual poles, while previous designs utilized solid cores with machined coil grooves. The winding procedure also changed from the first test cores to the current final design.

Details of the magnet structure's design, manufacturing, winding and jaw assembly, and changes made from the first prototype system to the production unit, are presented.

INTRODUCTION

In order for an insertion device to be installed onto the APS storage ring it must meet difficult magnetic field specifications, particularly the first and second field integrals and phase errors. [1] Standard hybrid permanent magnet undulators (undulator "A" type) require careful magnet sorting prior to installation of the magnets during undulator assembly. After assembly, the undulator is measured magnetically at all working gaps and the magnetic field is tuned by using multiple shims of different sizes to ensure that the magnetic field will meet the requirements of the APS.

One main advantage of a superconducting undulator (SCU) is that the electric current that creates the magnetic field is the same in each coil pack along the length of the device. Nevertheless, installations of shims inside the SCU cryostat after magnet installation and magnetic field measurements is very time consuming and impractical. Magnetic field errors can be corrected by having multiple built-in correctors or by having a sophisticated correction system, such as the one proposed by Lawrence Berkeley National Lab [2].

Our approach was to fabricate the magnet structure with maximum mechanical precision to preserve uniformity of the magnetic pole width and coil grooves for the superconducting wire to completely avoid shimming and achieve all necessary tolerances with only two small end correctors.

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MAGNET STRUCTURE DESIGN

Several planar SCU magnet structures with lengths of 0.4 meter, 1.1 meters (two), and 1.5 meters have been machined and wound with superconducting wire. We initially considered a core made of one piece with round corners of low carbon steel 1006-1008 for prototyping. This core had continuous grooves for the superconducting wire around the whole core. It required rotation of the core around its longitudinal z-axis to produce such grooves during the machining process. This is acceptable for a short core length, but will create machining challenges for cores of lengths greater than one meter. One other detail, which requires much attention, is the surface finish of the bottom of the coil winding groove and the groove side walls. The surface finish is required to be very smooth in order to avoid damaging the superconducting wire insulation during the coil winding process. Hand polishing of these surfaces could be very labor-intensive, and therefore, costly (see Fig. 1).

Figure 1: Initial core design.

The approach taken at the APS to simplify the manufacturing process and allow for a simpler polishing process is to start with a racetrack core. The racetrack core can be machined precisely with flatness on the face plane (the beam side) better than 50 microns over the whole length, and the surface can easily be polished. This polished surface ends up being the base of the winding groove.

The next operation is to machine precise grooves on the face plane with strict tolerances on the groove width, depth and location. To avoid an accumulated error in the pole location, each groove is machined from the same initial reference plane. The previously precisely grinded, polished, and lapped magnetic poles are then installed into these grooves, which results in an excellent surface finish for the superconducting wire groove. (see Fig. 2).

Such a design also allos for poles to be grinded after installation and with reference to the flat core plane to achieve uniformity of the depth of grooves for the superconducting wire coil packs. The poles are attached to the core with #1-64 screws.

The 33.6 cm long cores for the first prototype superconducting undulator, SCU0, were fabricated using this process and successfully passed all magnetic tests. [3]

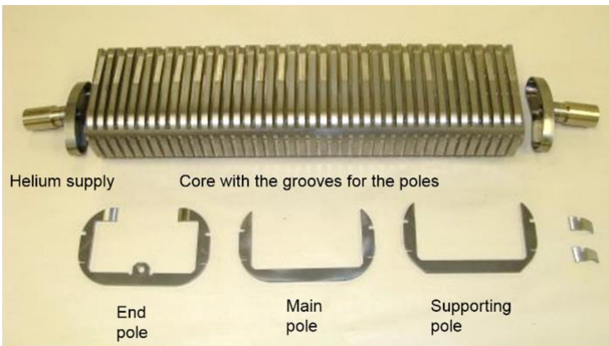

Figure 2: Core design modification.

To simplify this design and to make production of the core cheaper, we came to the next modification (Fig. 3). The machined grooves are now only on the core face side (1). The magnetic poles are simple rectangular pieces of two types: main poles (2) and poles with the end tabs (3), which are used to precisely join the top and bottom jaw.

To create grooves for the superconducting wire around the whole core (1), we added additional side spacers made of G10 (4). The side spacers are slightly narrower than the magnetic poles to allow for less restrictive tolerances during the machining and fabrication process. An added benefit of using G10 is the decreased probability of continuity between the superconducting wire and the steel core due to 2/3 of the winding groove side walls being made from an electrical insulator. Each G10 side spacer attached to the core body with two spring pins (5).

In addition, the winding procedure was also changed. SCU0 was wound by first winding all of the odd grooves in one direction and then changing direction of the conductor followed by winding all of the even grooves. After completion of the winding in the first groove, the conductor is transitioned to the adjacent groove using special pins (6) to make a 180° turn. The adjacent groove is then wound in the opposite direction. Pins are inserting in machined holes along the core one by one after completing the winding process in each groove. Pins will stay in their place when the winding is complete and the core is epoxy impregnated.

The final technological process of production of the magnet cores for the planar SCU is presented below:

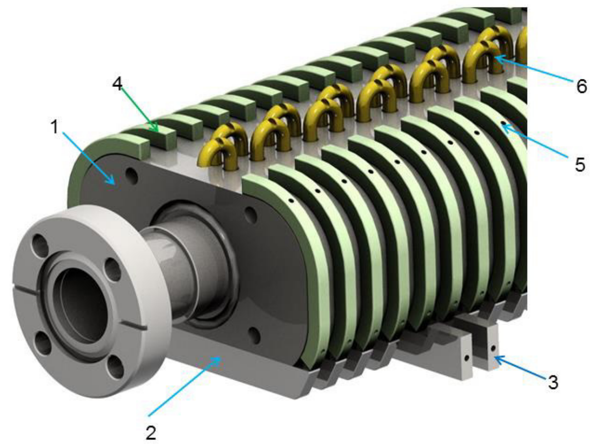

Figure 3: Final core design.

1. Preliminary machining of the core made of low carbon steel 1018 with annealing after it;
2. Final grinding of the core to achieve the best flatness (better than 50µm over the whole length) and the best surface finish;
3. Preliminary machining of the core made of low carbon steel 1018 with annealing after it;
4. Final grinding of the core to achieve the best flatness (better than 50µm over the whole length) and the best surface finish;
5. Machining grooves for the poles avoiding accumulation errors;
6. Machining, grinding, annealing, and final lapping of the poles, made of 1006 steel, to achieve the best surface finish and dimensional uniformity within 10 µm;
7. Pole installation inside core grooves using “go” “no go” gages and #1 screws;
8. Grinding of the pole face side with the reference to the core face plane to get maximal uniformity of the groove depth for winding;
9. Inspection of the all-critical dimensions (groove depth and width, pole face flatness along the whole core). Inspection is made two times— at vendor place first and then in house before winding.

CONCLUSION

Based on the current approach, we made five 1.1-meter-long cores and three 1.5-meter-long cores (Fig. 4). We were able to get the same tolerances as for the first 40-cm-long cores. Phase errors of less than 3 degrees were achieved on the 1.1-m-long magnet with only two end correctors. 1.1-meter-long cores were constructed to replace SCU0. [4].

Figure 4: 1.5-meter-long cores prepared for shipment.

All cores were made by "Hi-Tech Manufacturing LLC" (Schiller Park, IL). Developed technology could be transferred to a different vendor who has the same precise machine tools if necessary.

REFERENCES

[1] Yong-Chul Chae and Glenn Decker, "Advanced Photon Source Insertion Device Field Quality and Multiple Error Specification." CERN, Particle Accelerator Conference, 1996 IEEE.

[2] D. Arbelaez *et al.*,"Magnetic Field Correction Concepts for Superconducting Undulators." IEEE Transactions on Applied Superconductivity, vol. 23, Issue: 3.

[3] Y. Ivanyushenkov, M. Abliz, ,K. Boerste, E.M. Trakhtenberg *et al.,* "Status of the First Planar Superconducting Undulator for the Advanced Photon Source," in *Proc. IPAC-2012,* New Orleans, USA, May 2012.

[4] Y. Ivanyushenkov, C. Doose, J. Fuerst, K. Harkay, Q. Hasse, D. Skiadopoulos, E.M. Trakhtenberg, *et al.*, "Development and Performance of 1.1-M Long Superconducting Undulator at the Advanced Photon Source," in *Proc. IPAC-2015,* [2] *Manual*, IEEE Periodicals, Piscataway, NJ, USA, Oct. 2014, pp. 34-52.