

TIGHTENING THE TOLERANCE BUDGET OF CORE FABRICATION TO ACHIEVE HIGHER MAGNET PERFORMANCE

Nanyang Li, Arnaud Madur, LBNL, 1 Cyclotron Rd. MS71-259, Berkeley, CA 94720, USA

Jiang Jin, SINAP, 2019 Jialuo Rd. Jiading district, Shanghai, China

Abstract

Traditionally, laminated cores of AC magnets have been always built by the laminations that are produced by a punching die. There are 5 links in the tolerance chain when a magnet core is built by this procedure: 1. Error of punching die; 2. Error of lamination punching; 3. Error of half core stacking; 4. Error of core assembly; and 5. Error of magnet re-assembling during the installation in the accelerator. As time goes on, the Lattice physicists call for more and more ever higher magnet performance, which makes the required magnet field quality almost impossible achieve by traditional core fabrication procedures. It is the goal of this paper to describe a relatively new procedure that was first used by Buckley System Ltd, NZ and is being used at SINAP, China for ALS combined function sextupole core fabrication. The advantage of this new procedure and the fabrication issues related to this procedure will be described in this paper.

THE DEVIATIONS OF A CORE BUILT BY PUNCHED LAMINATIONS

Lamination Precision

Fig. 1 is the core assembly of a SLAC SPEAR3 sextupole magnet which was built at IHEP in China. The core was built by three 1/3 cores and 3 solid blocks. The 1/3 core was stacked and glued 0.5mm thick punched laminations. Fig. 2 is the segment (point 1 to point 24) of two poles on a lamination. The features from point 1 to 2 and point 23 to 24 are datum planes of the core assembly and point 5 to 8 and 17 to 20 are pole tips, which affect magnetic field quality. IHEP shipped three laminations to SLAC after a punching die trial, and SLAC conducted CMM inspection on them. Fig. 3 shows the deviations among three laminations from point 1 to point 24. One can see, the maximum discrepancy from lamination to lamination at pole tips (in orange frames) is about 0.06mm, which might be caused by shifting of the gap between the punch and die during the lamination punching process or by lamination burr size. Therefore even using an IHEP built die that was called at an accuracy of fabrication as small as $\pm 0.0125\text{mm}$, final lamination precision that was reached after punching was much larger than the die precision.

Precision of 1/3 Core Stacking and Assembly

After punching laminations, the laminations were stacked and glued in a stacking fixture and cured in an

oven into a solid piece of 1/3 core. As shown in Fig.1, there are two types of gaps in the SPEAR 3 sextupole magnets: fixed and unfixed. Theoretically, the fixed gap would not change during the core assembly, since it was produced by a punching die and was a fixed feature on a lamination. But in reality as shown in fig. 4, among 47 SPEAR3 sextupole magnets, those fixed gaps deviated from the nominal dimension in a 0.03mm tolerance zone. This deviation was a combination of



Figure1: SLAC, SPEAR3 Sextupole Core.

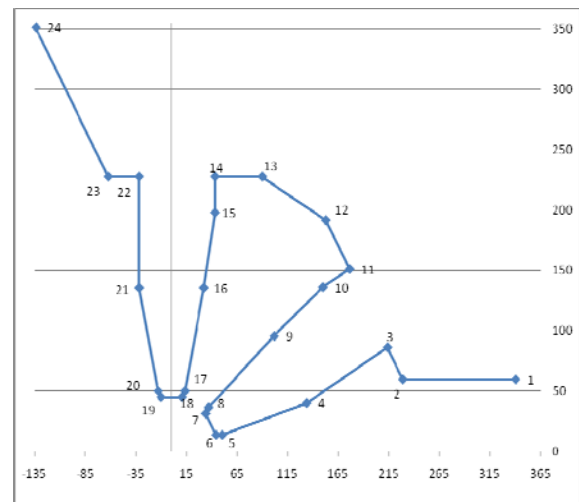


Figure2: SLAC, SPEAR3 Sextupole Lamination.

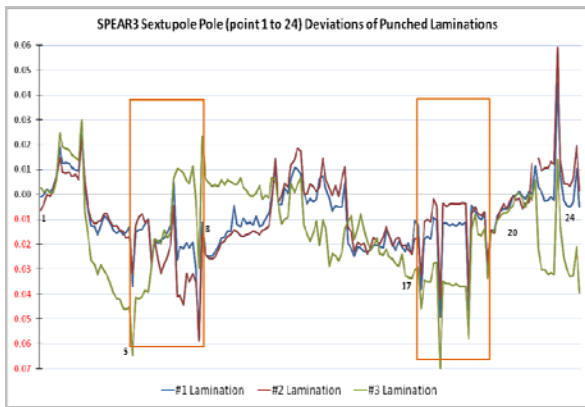


Figure3: Pole Deviations of 3 SPEAR3 Sextupole Laminations.

punching process and stacking error. Unfixed gaps were created during the core assembly between poles of two adjacent 1/3 cores, their deviations among 47 SEPAR3 sextupole magnets are as shown in Fig. 5. One can see, those gaps had a much larger discrepancy among magnets, which scattered from max. +0.09mm to -0.04mm.

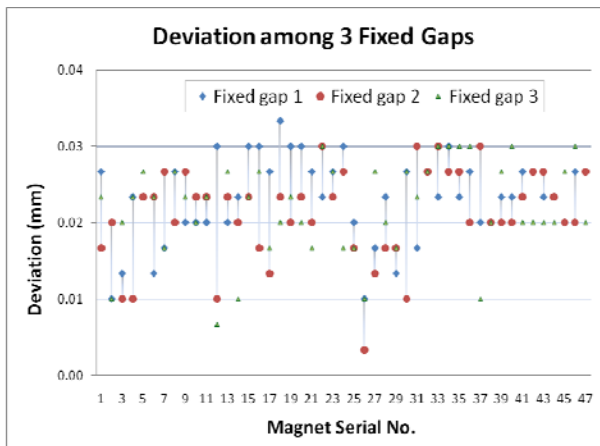


Figure4: Gap deviation caused by stacking.

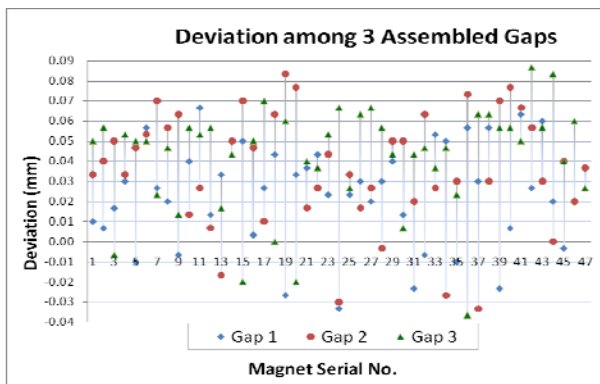


Figure5: Gap deviation caused by assembly.

Precision of Core Apertures and Magnetic Centre Offset

In addition to those gaps, the apertures between 3 pairs of

pole tips were checked, which is another important step to ensure the precision of a sextupole magnet after assembly. Fig. 6 shows the deviations of apertures among 47ea SPEAR3 sextupole magnets. One can see, they were scattered over a quite large range.

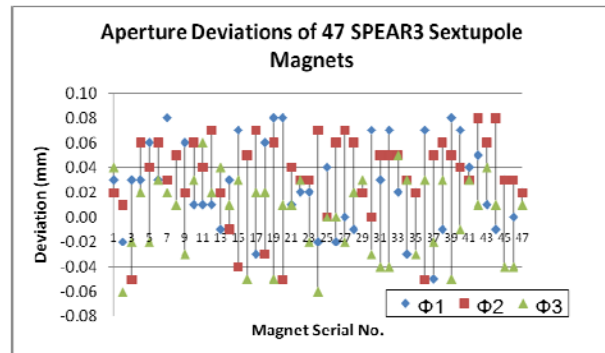


Figure 6: Aperture deviation caused by assembly.

It is very difficult to precisely position 6 poles to get higher uniformity of apertures between pair of poles using laminated 1/3 core assemblies. Consequently, the magnetic centres of those sextupole magnets were scattered as well (refer to fig. 7).

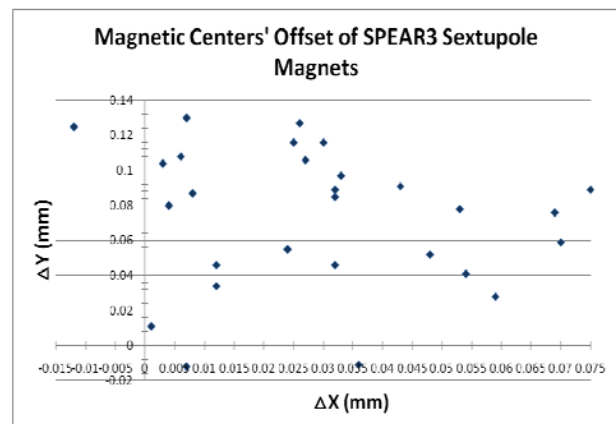


Figure 7: Magnetic center scattering caused by misalignment of core assembly.

A total of fifty-one combined function magnets is required to upgrade the Advanced Light Source Storage Ring at LBNL. These magnets will provide 4 types of magnetic field: sextupole, horizontal & vertical dipole, and skew quadrupole. The specification requires that when excited at maximum currents, all the magnets of one type shall produce the same main field within 0.1% for a given type of field (sextupole, vertical dipole, horizontal dipole and skew quadrupole). The magnet orientation about the z-axis shall be measured with an accuracy of +/-0.03 mrad or better and a precision of 0.06 mrad or better. After an initial magnetic measurement, the magnet yoke shall be disassembled and assembled again, and a second magnetic measurement carried out. The magnetic measurement results shall agree to within 0.01% [1].

Because of the chain of tolerances stated above, it is

very hard to reach these goals for a magnet that will be built by the traditional method of a laminated core. The SINAP workshop that was awarded the ALS sextupole magnet contract, proposed to EDM cut all six poles after core assembly. Still, laminations will be punched and stacked and glued into 1/3 core. The difference of this method from the traditional way is that the pole tips will leave a margin from the final dimension during the punching process, and the EDM is conducted after the core is assembled, screwed and dowel pinned into one piece (refer to fig. 8).

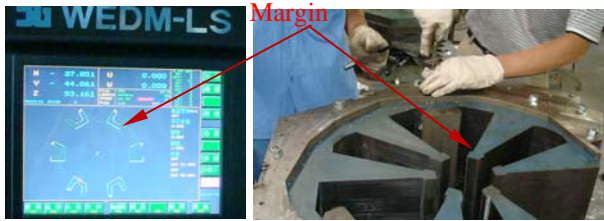


Figure 8: EDM cut pole tips after core assembly.

CORE EDM CUT FROM A SOLID PIECE

EDM Process and Precision

In this process, the cut is continuous. Take the ALS G type sextupole magnet as an example, the core is 200mm long, and it takes 4 cuts to reach the final precision of the poles. The entire procedure of the prototype core cut took 20 hours. The EDM was programmed with the final shape profiled by X and Y coordinates. The first cut reached the ideal profile and three more trim cuts followed afterwards with the poles reaching final precision after the last touching cut. There were no wires broken or wires stuck during the processing. SINAP CMM inspected the prototype core cuts, the majority of segments of the poles stayed within a 0.01mm tolerance zone. The maximum offset is 0.04mm at a broken line corner. Since the core was dowel pinned by 4 horizontal pins and 4 vertical pins, the repeatability of reassembly (1/3 cores were disassembled and assembled again) was as good as $< \sim 0.005\text{mm}$ based on the CMM inspection at Buckley System Ltd, NZ. Since SINAP is still completing the fabrication of prototypes, more statistics values are not available at the moment.

Potential Problem of EDM Cut Pole

During the EDM process, it is almost impossible to avoid building some cutting beads, which may short lamination to lamination. In the ALS sextupole magnet case, since the vacuum chamber is made from aluminium, the effect of possible eddy currents caused by shorting of laminations is negligible compared to the effect of a piece of vacuum chamber 2-3 mm away from the pole tips. We took few micrographs on an EDM cut pole tip to observe the connection among laminations by those possible cutting beads. The laminations are well separated by their coating, but some boundaries are smeared as shown in fig. 9.

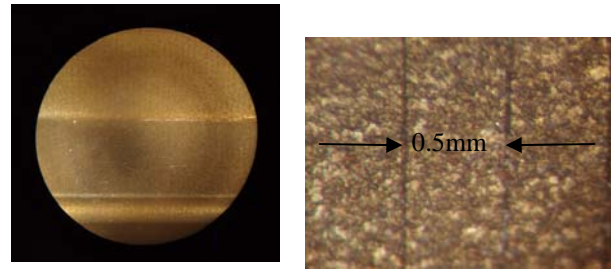


Figure9: Smeared boundary of laminations.

This might be a problem for an AC magnet, should its field be very sensitive to the property of the pole tip material. Further studies of the effect of smeared boundaries of laminations during the EDM process shall be conducted if this is the case.

CONCLUSION

Based on the discussions above a magnet core that is built using 1/2 or 1/3 cores with poles that are EDM cut after assembling into one piece will have a precision equal or better than the tolerance achieved by punching die fabrication. The EDM process of cutting a core from a single piece will reduce the FIVE links in the tolerance chain of traditional fabrication of a laminated core to ONE, which will substantially increase the accuracy of magnet manufacture. It will make it possible to obtain the same accuracy during the installation of the magnet into the accelerator, which will generally involve disassembly of the magnet in order to install a vacuum chamber in the aperture.

Therefore, EDM cut poles after core assembly is a very promising procedure for laminated magnet fabrication. It needs less skill for technicians who conduct the magnet assembly and obtain a high manufacturing accurateness of a magnet rather easily. The higher performance of the magnet after installing into the ring will be ensured, as well.

REFERENCES

- [1] A. Madur and N. Li, "Combined Function Magnet Specifications" (2010)