

A SUMMARY OF THE QUALITY OF THE ALS COMBINED FUNCTION SEXTUPOLE MAGNETS

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Abstract

A total of forty eight combined function magnets is required to upgrade the Advanced Light Source (ALS) Storage Ring at LBNL. These magnets will provide 4 types of magnetic fields: sextupole, horizontal and vertical dipoles, and skew quadrupole and will enable an emittance reduction and upgrade of the beam quality in the ALS ring. A relatively new procedure using EDM cut poles after core assembly that was first used by Buckley System Ltd, NZ was adopted during the production of these magnets. Also, a new 3D CAD modeling was used for the coil design. A total of 57 magnets (including prototypes and spare magnets) were built by the Shanghai Institute of Applied Physics (SINAP) in China. These magnets have achieved extraordinarily high pole profile accuracies and exhibit excellent coil performance characteristics: resistances and water flows reached a high degree of consistency. Consequently, the system errors of the magnetic field of these magnets all meet the LBNL specifications. This paper will summarize the mechanical quality and magnetic field properties of these magnets. The interrelationship between the qualities of coil and the magnet field will be described as well.

92mm. The aperture dimensions obtained after EDM cut showing in orange and the ones measured after coil assembly showing in blue. Three charts show that 3 aperture dimensions between diagonal poles of total 25 E type sextupole magnets are well within a pocket of 0.05mm (+0.03mm /-0.02mm) after coil assembly. Fig. 3 shows the aperture deviation of 25ea sextupole magnets for SLAC SPEAR3 project, which were built by traditional method. The offset range of those magnet apertures is +/-0.1mm. Obviously, the accuracy of core apertures of SINAP built sextupoles have been improved greatly.

POLE PROFILE ACCURACIES

ALS sextupole core fabrication adopted a relatively new procedure using EDM cut poles after core assembly¹. Fig. 1 is a CMM plot showing the actual EDM cut pole profile of G type sextupole core. The red lines are the tolerance zone ($\pm 0.0125\text{mm}$) and the blue lines are the true profile of the poles. One can see, the blue lines all stay in the tolerance zone. This kind of poles' profile quality cannot be reached by traditional core assembly procedure – lamination stacking.

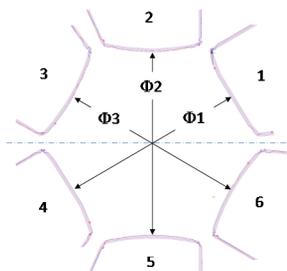


Figure 1: CMM plot of G type sextupole core.

Fig. 2 is E type sextupoles' pole apertures comparison between the ones measured right after EDM cut and the ones after coils assembly – core disassembly and reassembly. The nominal aperture of E type sextupole is

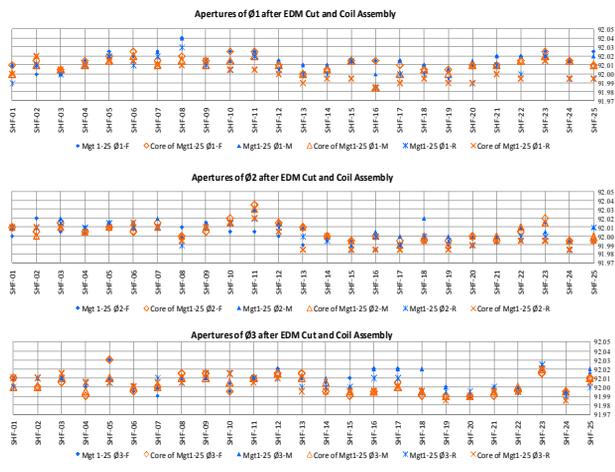


Figure 2: Precision of E type Sextupole Apertures.

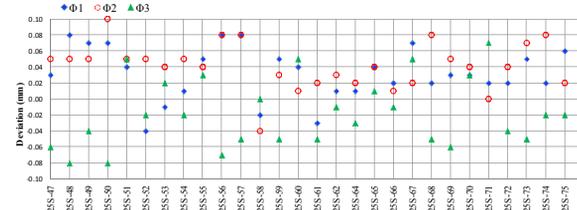


Figure 3: Deviation of SPEAR3 Sextupole Apertures.

HIGH GRADE COIL PROPERTIES

A new 3D CAD modelling was used for ALS sextupole coil design². The consumption of conductor (measured by weight and length) and the method of transition from layer to layer and from circle to circle all were indicated in the design drawing of each type of coil. The information of conductor consumption and the winding method were recorded step by step in the traveller during the coil winding by the technicians and were checked by LBNL onsite inspector. The properties of coils come out from all these efforts are very

satisfactory. Fig. 4 shows the resistances of 5 type coils of E type sextupoles: sextupole field coil (total 180ea), large vertical dipole coil (total 60ea), small vertical dipole coil (120ea), horizontal dipole coil (120ea) and skew quadrupole coil (total 60ea). The resistances of those coils deviate from the nominal data are within a 5% range, which consequently provided a very good probability to select the coils and make the deviation of same type coils in one magnet is as small as 1%. Because of the consistence of the conductor length consumption, the water flow quantity of each coil is in accordance with expected nominal value, as well.

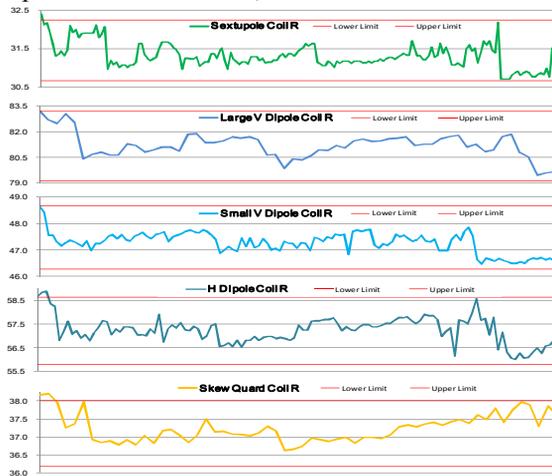


Figure 4: Resistances of E type coils.

THE IMPACT OF COIL RESISTANCE TO THE MAGNETIC FIELD OF A MAGNET

During the G type sextupole prototype fabrication, SINAP workshop replaced main field coils – sextupole ones on those core poles few times and conducted magnetic field measurement after each coil replacement. Fig. 5 shows the resistance scenarios of these coil changes. In the 1st coil scenario, the margin between max. and min. coil resistances is 14.95% of average resistance of 6 coils. The SINAP shop therefore produced few more sextupole coils and changed the coils on the prototype until the deviation being reduced to 1.97% in the 4th scenario.

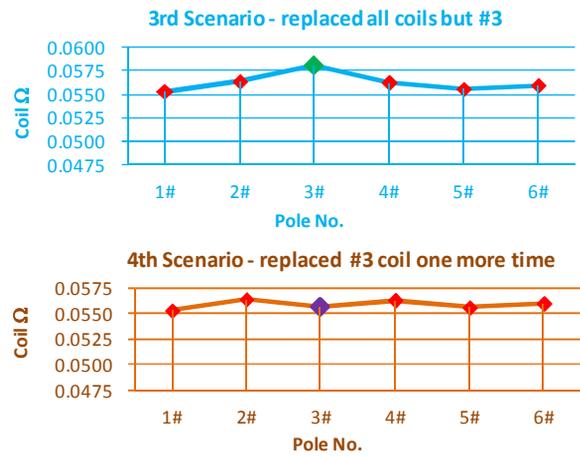
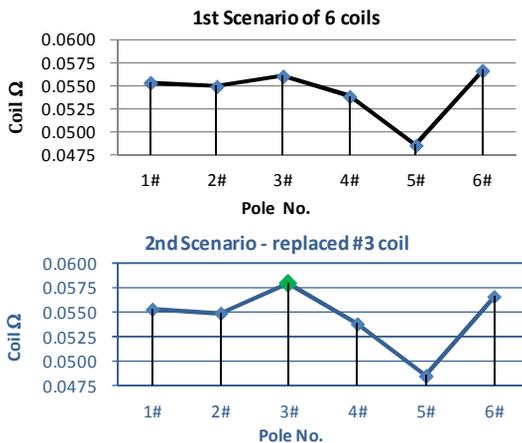


Figure 5: Coil resistance scenarios.

The main field peak curves of each coil scenario are shown in fig. 6. The strength variation between max. value and min. value in four scenarios are 4.61×10^{-3} , 2.39×10^{-3} , 9.2×10^{-4} and 2.14×10^{-3} (V*s) respectively. Fig. 7 shows the system harmonics of main field in all coil scenarios. One can see the 3rd coil scenario has the best result, which indicates that the smaller the resistance variation among coils, the better the field uniformity. Based on this study, the coil resistance criterion was set up for the magnet production, thereafter: the deviation among all coils of one type shall be less than 5% of average resistance of first 4 coils, and the deviation among same type of coils in one magnet shall be less than 1%. Since the magnet assembly was started at dozens of coils of each type had been produced, the setup standard was reached easily during the production.

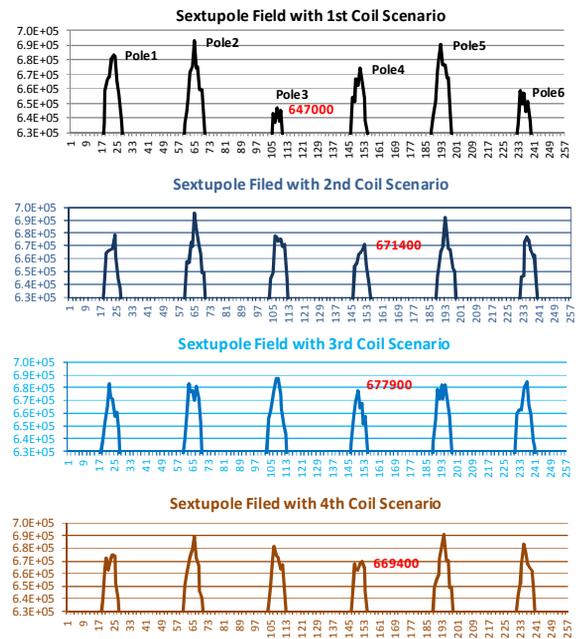


Figure 6: Sextupole field peak curves (V*s) under operation current of each coil scenario.

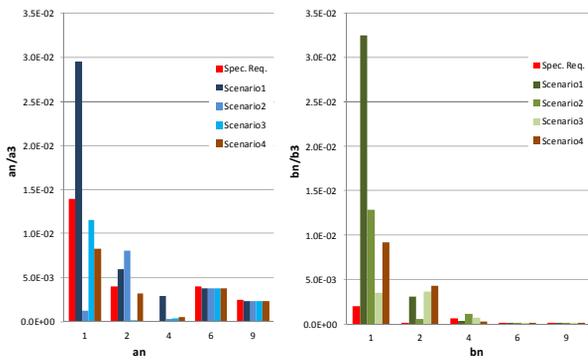


Figure 7: System harmonics of sextupole field in different coil scenarios.

EXCELLENT FIELD QUALITY

SINAP used a rotating coil magnetic field measurement system to test the integral field of all ALS sextupole magnets. The errors of $bn=1$ and $bn=2$ over the main field were measured with unbuckled mode of the rotating coil and the higher harmonics were measured with bucked mode of the rotating coil. The rotating coil center was aligned precisely ($<0.05\text{mm}$) with the center of magnetic field of the sextupole magnet before the data acquisition. The collected data were normalized to the center of the magnet field with the correction of the slight X and Y offset between the magnetic field center of the magnet and the rotating coil center afterwards. The data collected from dipole and quadrupole field measurement were regulated upon the skew angle of main field being obtained with unbuckled mode. The charts in fig. 8 is a summary of multipole errors of main field of all G type sextupole ($an/A3$ and $bn/B3$).



Figure 8: Type G sextupole multipoles of main field.

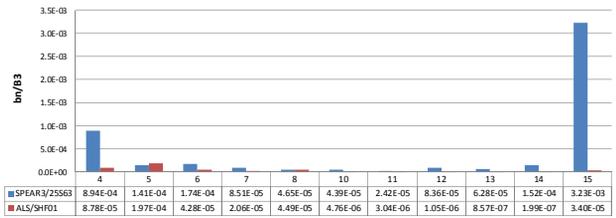


Figure 9: Multipoles comparison between SPEAR3 sextupole and ALS sextupole.

In order to see the great magnetic field qualities of ALS sextupole magnets, we did the comparison between the sextupole field of SPAER3 sextupole and ALS sextupole. The former ones were built by traditional core fabrication method and the norm of variation among the coils on one magnet is 5%. The blue bars in fig. 9 are of SPEAR3 sextupoles and the red bars are of ALS sextupole. The multipoles of ALS sextupole are reduced one order of magnitude at each harmonic.

CONCLUSION

By the end of March 2013, all sextupoles have been successfully installed in the Advanced Light Source ring in LBNL during two months maintenance shutdown and they are currently used to produce a brighter photon beam as expected. The EDM cut poles procedure of core fabrication and the 3D CAD modelling of coil winding design are the key factors for obtaining precise symmetry of the poles and super consistency of the coil properties. Indeed, SINAP's attention to quality control throughout the entire magnet fabrication process was crucial to the successful performance of the ALS combined function sextupoles.

REFERENCES

- [1] "Tightening the tolerance budget of core fabrication to achieve higher magnet performance" WEPO22, IPAC11
- [2] "Accurately determining the parameters of a magnet coil by 3D CAD design" THPPD019, IPAC 12