FIELD QUALITY FROM TOLERANCE ANALYSES IN TWO-HALF SEXTUPOLE MAGNET

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ABSTRACT

Sextupole magnets are used extensively in particle accelerators, synchrotrons, and storage rings. Good magnetic field quality is needed in these magnets, which requires machining the magnet parts to high precision and is the primary driver of the high fabrication costs. To minimize the fabrication costs, a magnetic field quality study from tolerance analyses was conducted. In this paper, finite element analysis (FEA) using OPERA was performed to identify key geometric factors that affect the magnetic field quality and identify the allowable range for these factors. Next, geometric and dimensional tolerance stack-up analyses are carried out using Teamcenter Variation Analysis to optimize the allocation of the geometric tolerances to parts and assemblies. Finally, the analysis results are compared to magnetic measurements of a R&D sextupole magnet.

OBJECTIVES

- Identify the key features that affect the magnetic field quality in the two-half sextupole magnet design
- Determine the appropriate tolerances for the identified key features
- Determine the appropriate mechanical tolerance to achieve the desired magnetic quality
- Determine the part and assembly level tolerance and fabrication plan

DESIGN REQUIREMENTS

- Magnet parameters

Magnetic Requirements		S1/S3	S2
Insertion length	m	0.230	0.260
$B''L$ (nom.)	T/m	764.8	1250.3
$B''L$ (max.)	T/m	918	1500
Operating range (wrt nom.)	%	50-120	50-120
Vertical BL (max.)	Tm	0.0087	0.0099
Horizontal BL (max.)	Tm	0.0073	0.0084

- Nominal systematic fractional multipole errors and allowable rms values for random fractional multipole errors for sextupoles at 10 mm radius

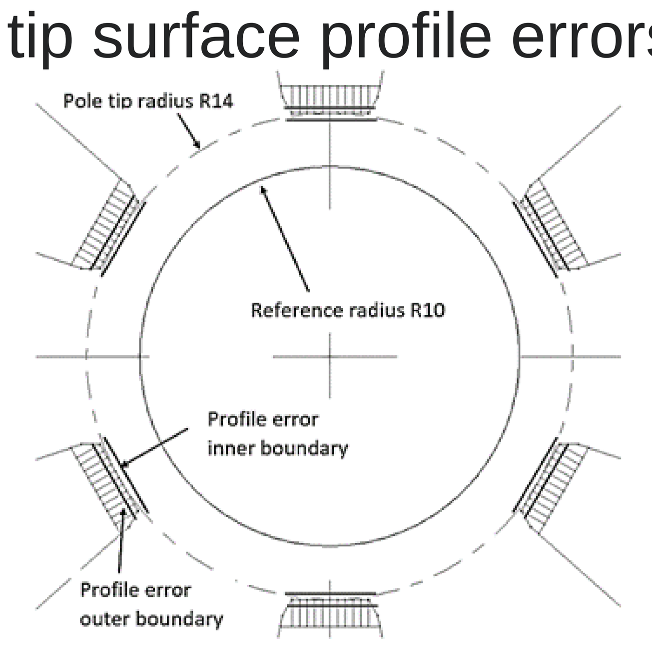
Order	Normal 10^{-4}
8	-303
14	-14

Harmonic	Normal (unit)	Skew (unit)
Octupole	8.9	8.9
Decapole	9.1	9.1
Dodecapole	4.5	0.9
14-pole	2.6	1.8
16-pole	0.7	0.7
18-pole	0.8	0.3

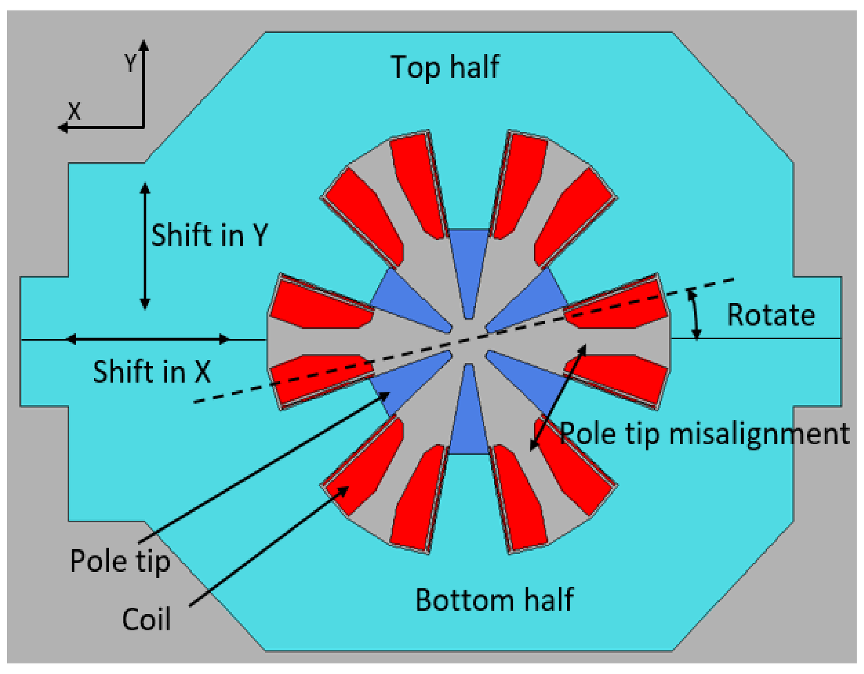
- Magnet to magnet alignment 30 μm rms
- Magnetic roll angle less than 0.4 mrad rms
- Magnetic center close to mechanical center

FEA MAGNETIC ANALYSES

- Pole tip surface profile errors

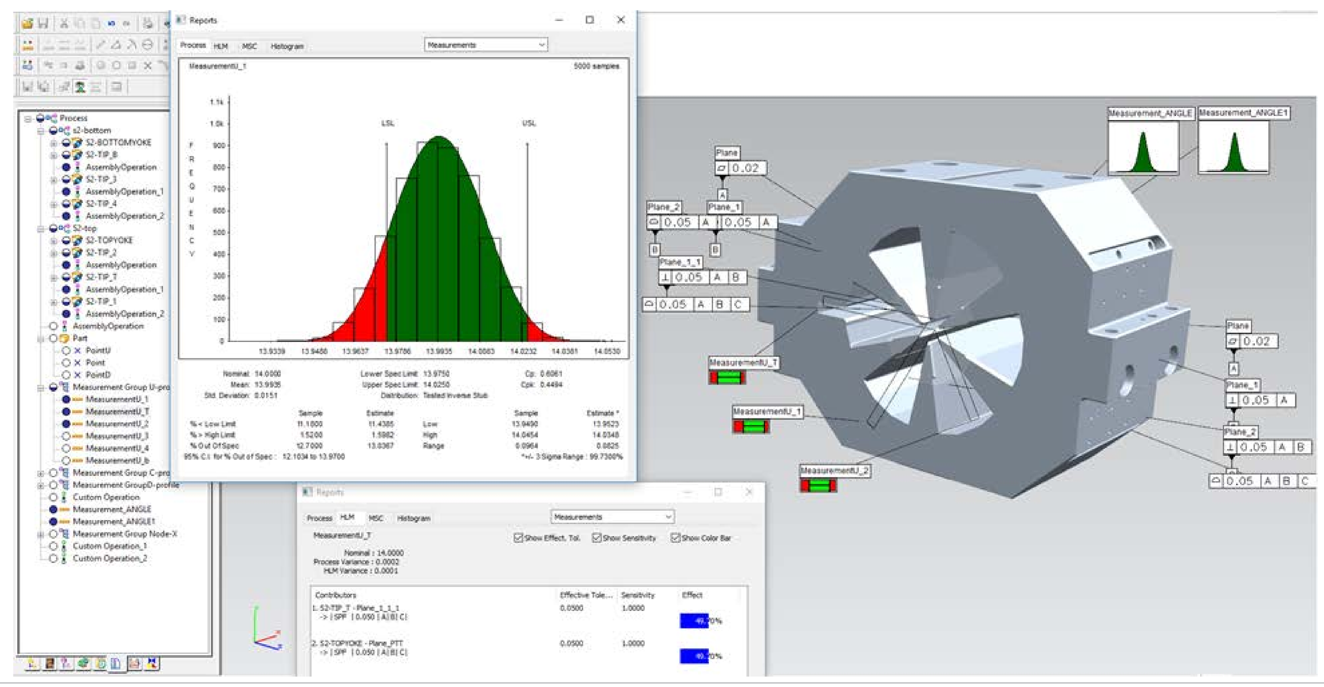


- Top half offset horizontally
- Top half offset vertically
- Top and bottom half relative rotation
- Pole tip misalignment

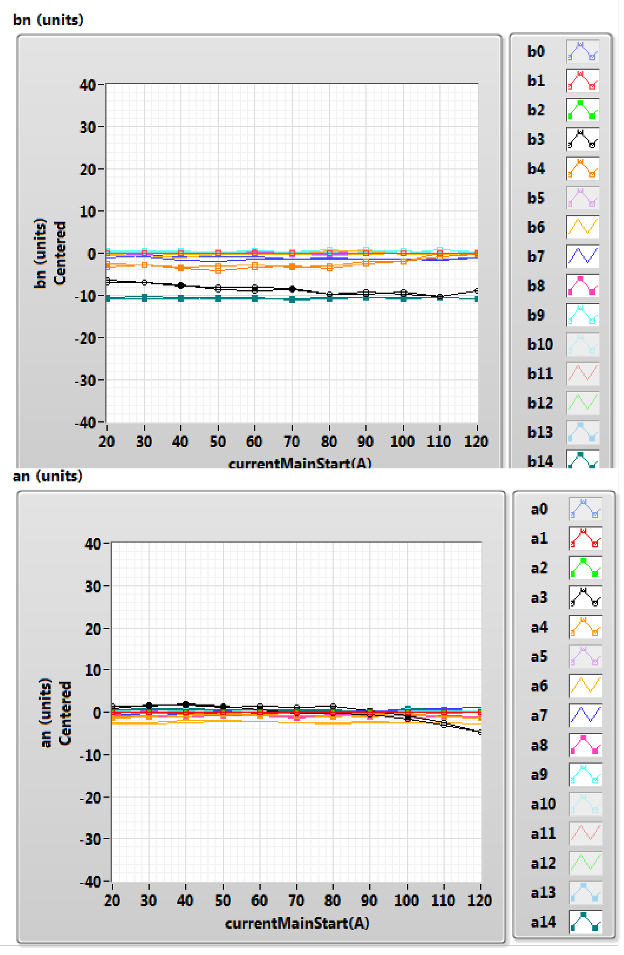


MECHANICAL TOLERANCE ANALYSES

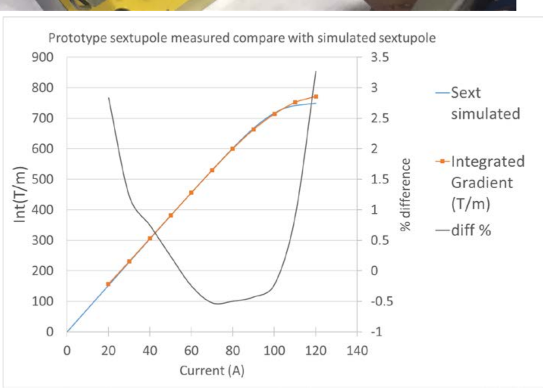
- Monte Carlo Method
- Virtually made, assembled, and measured in the same manner as in real world



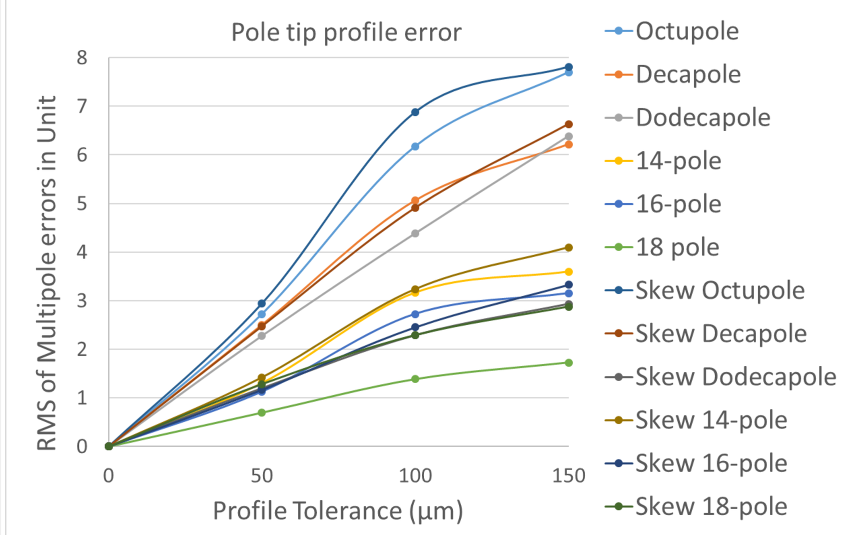
PROTOTYPE AND MEASUREMENTS



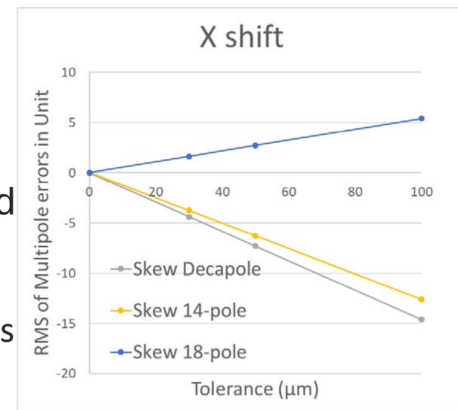
Measurement matches simulation very well

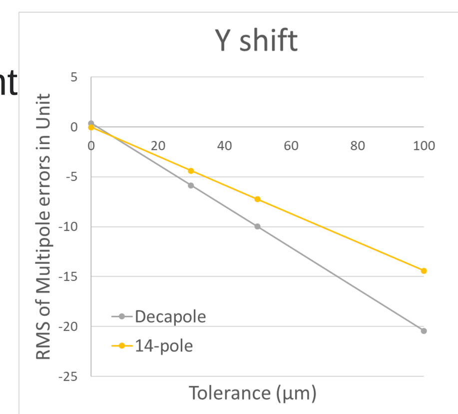


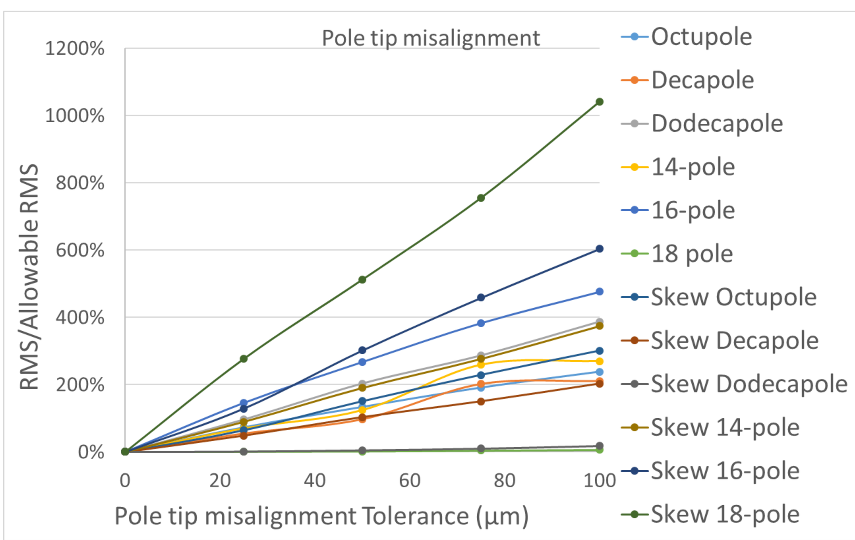
SIMULATION RESULTS



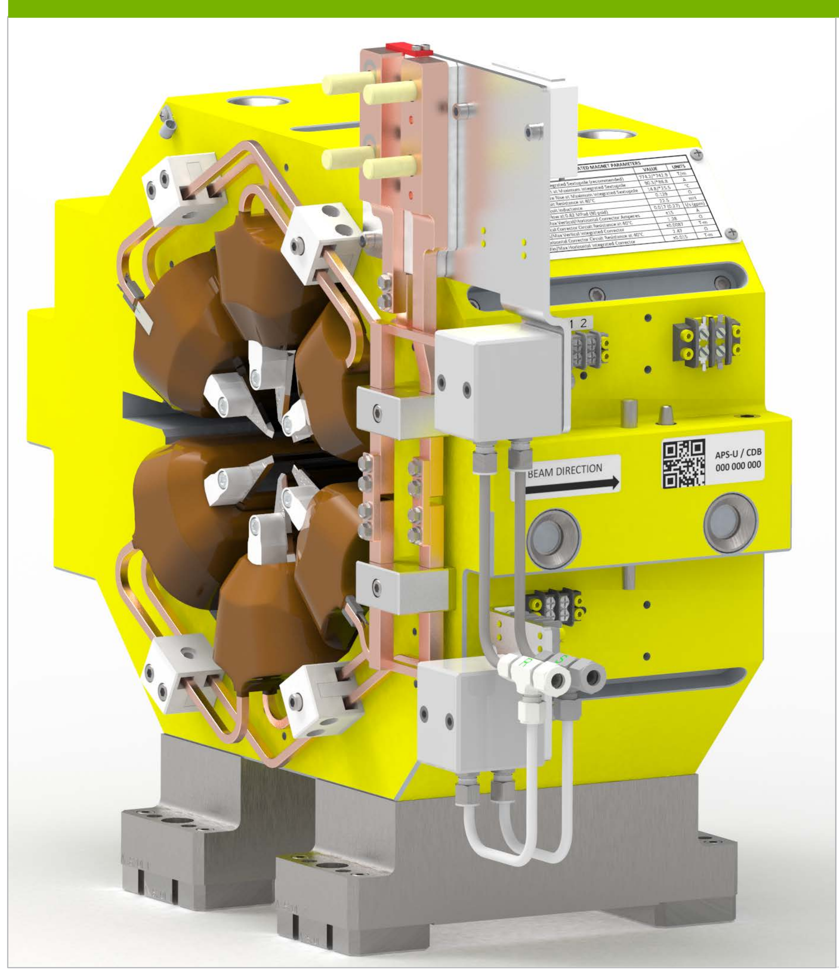
- Pole tip profile need be ≤ 25 μm
- Yoke and pole tip machining error need be ≤ 25 μm
- Mating surface flatness and coplanarity need be ≤ 20 μm
- Pole tip misalignment need be < 20 μm
- Difficult to achieve using conventional machining method
- Repetitivity need be addressed







FINAL DESIGN FOR PRODUCTION



- Two-halve design
- Wire EDM pole tips assembled
- Taper dowel pins to align top and bottom
- Metal filled epoxy keys for high repetitivity
- Removable side and bottom pads for center location control
- Robust and modular water and power system design

CONCLUSIONS

- Machining and assembly precision need be better than 25 μm. It is expensive to achieve using conventional fabrication and assembly methods
- Wire EDM the pole tips in an assembled state is needed
- Taper dowel pin and metal filled epoxy keys are developed to achieve good alignment repeatability of pole tips and yokes

REFERENCES

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Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC. The Advanced Photon Source is a U.S. Department of Energy Office of Science User Facility operated for the U.S. Department of Energy Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

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