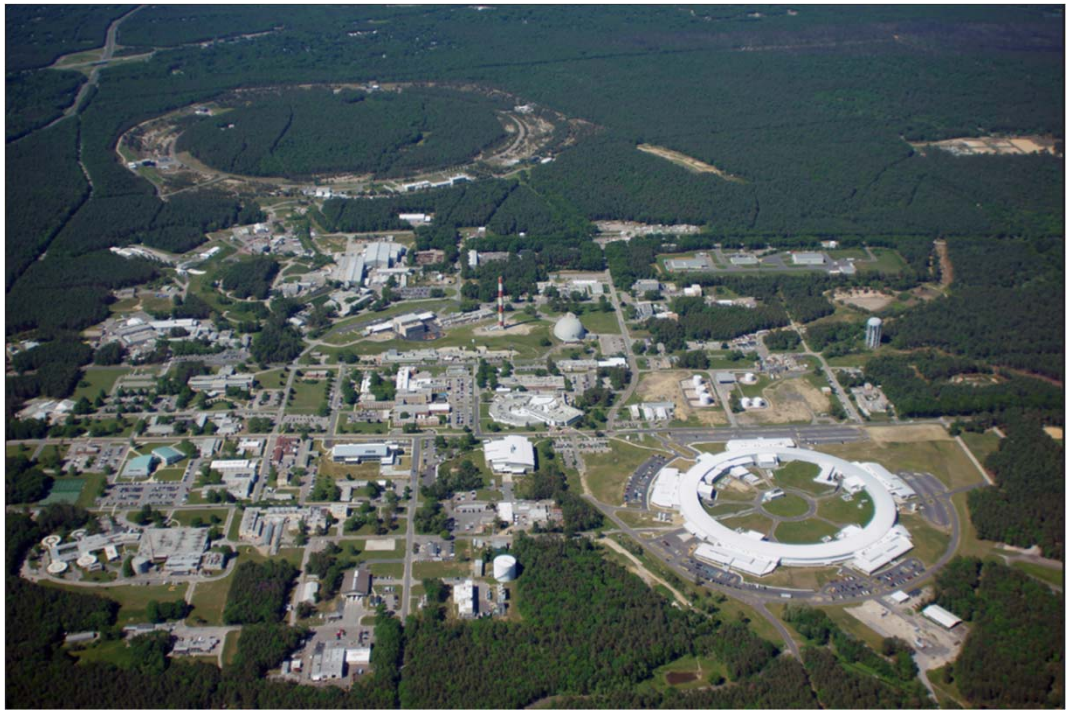
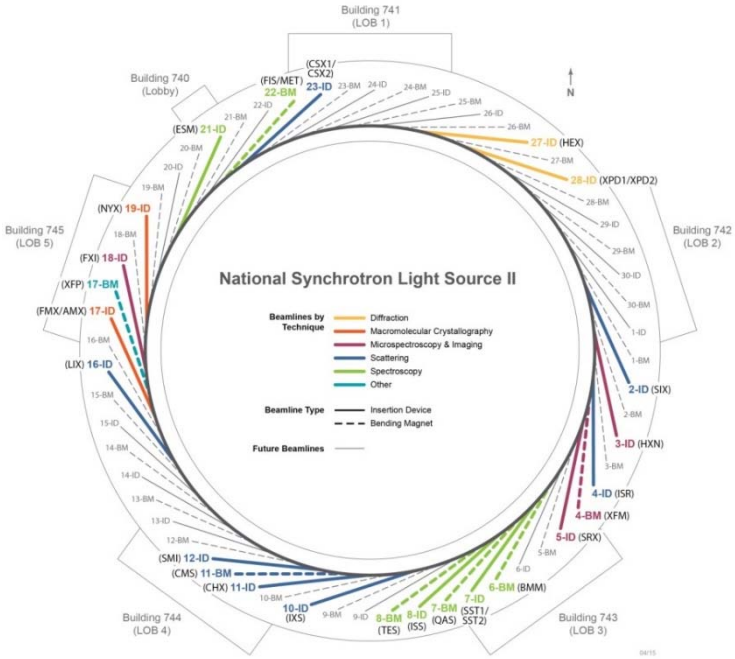
Fiducialization Precision of Mechanical Method





- A 3 GeV, 500 milliamp electron storage ring
- 20+ operational beam lines, 400 milliamp

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Outline

1. Overview
2. Magnet center based on mechanical feature
3. Magnetic center determined by vibrating wire
4. Deviation between magnetic and computed mechanical center
5. Summary

1. Overview

Table 1 Alignment Tolerances

Tolerances	Magnet to magnet on a common girder	Girder to girder	Globally
Horizontal positioning	± 0.030 mm	± 0.10 mm	± 3 mm
Vertical positioning	± 0.030 mm	± 0.10 mm	± 3 mm
Longitudinal	± 0.50 mm	± 0.50 mm	
Roll angle	± 0.50 mrad	± 0.50 mrad	

Assembly Weight: 8000 Kg

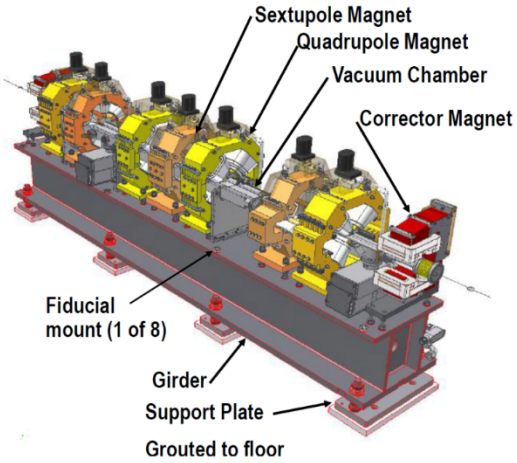
Overall Length: 4.8 m

Overall Width: .86 m

Overall Height: 63"

8 point support system

All components are independently adjustable



Fiducialization

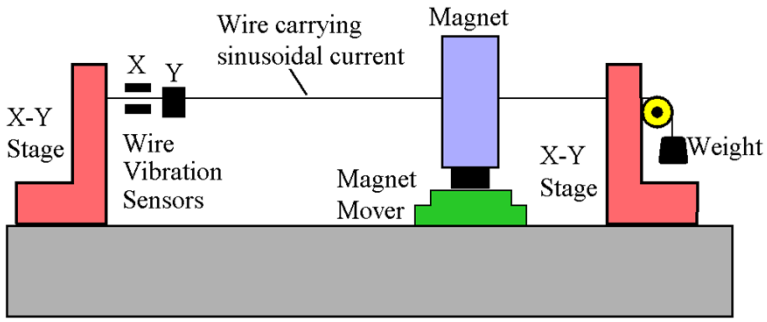
- One of the fundamental alignment tasks
- Mechanically (pole tips)
- Magnetically (integrate with rotating coil)
- Vibrating wire

Accuracy

- <100 micron (with laser tracker)
- <10 micron (with vibrating wire)

Goal:

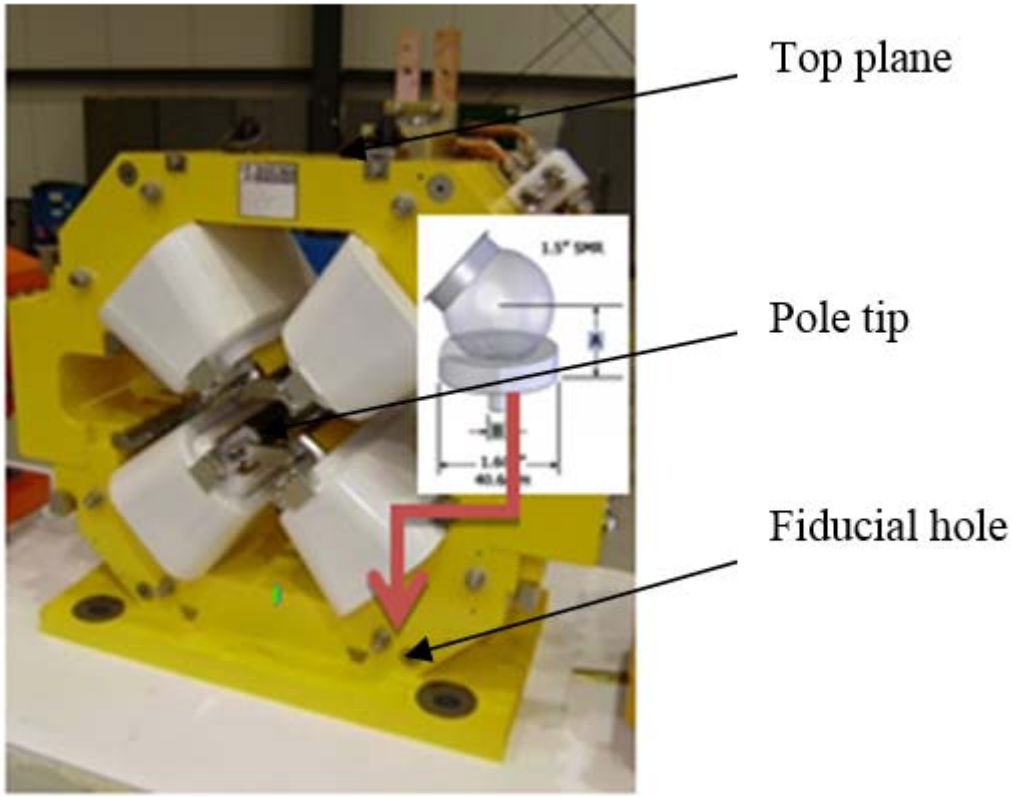
- By comparing with vibrating wire data, estimate fiducialization precision of mechanical method.



2. Magnet Center Based on Mechanical Feature (1)

Goal of magnet survey

- Check key dimensions and make sure specification is achieved.
- Get a set of fiducial data to be used to align magnets coarsely



Features

- Pole tips
- Plane
- holes

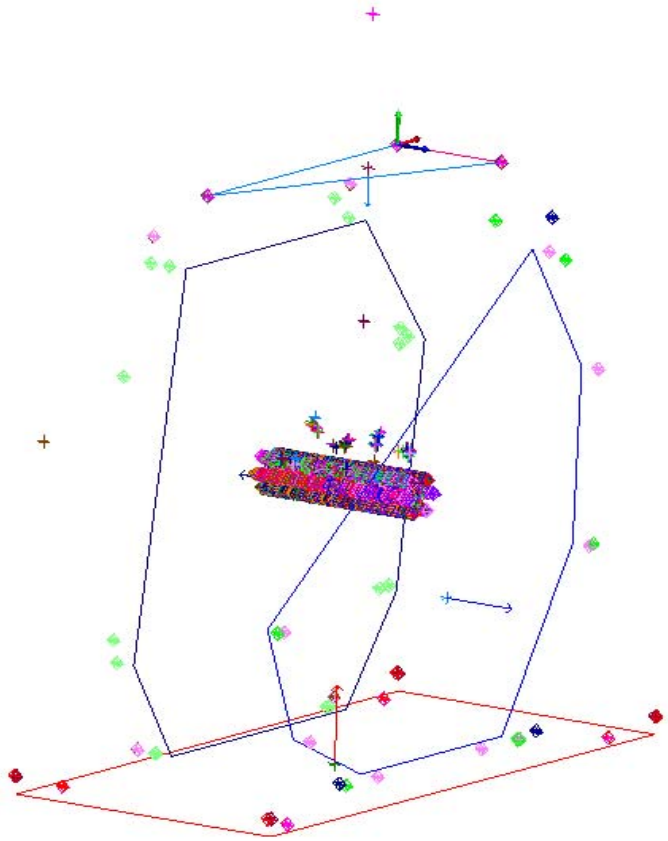
2. Magnet Center Based on Mechanical Feature (2)

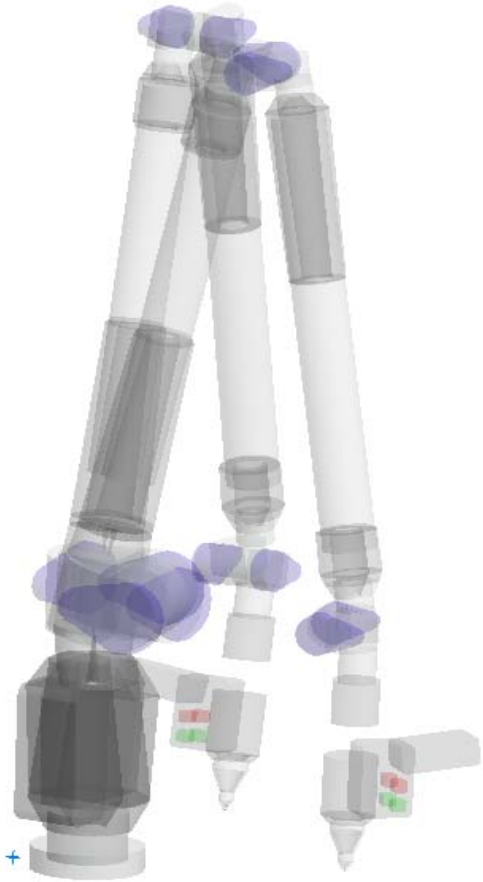
Approach

- Arm
- All features
- Repeat 5 times

Accuracy

- Instrument
- Temerature (8 °C yearly)
- Fiducial type

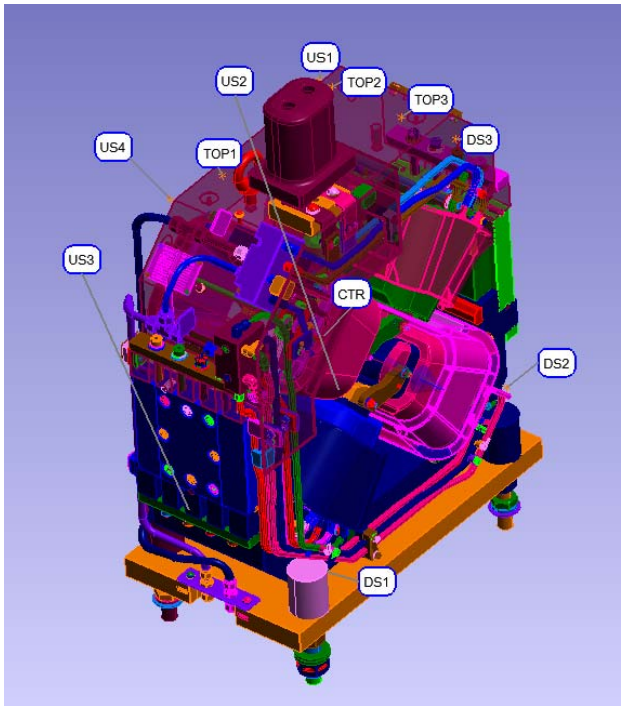


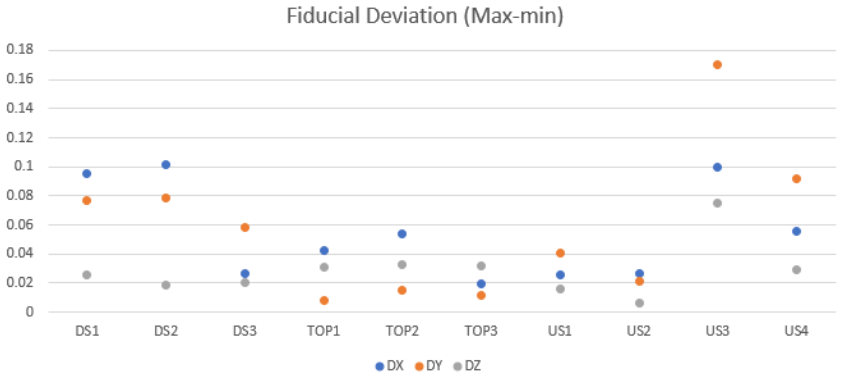


2. Magnet Center Based on Mechanical Feature (3)

Fiducial repeatability

- Hole type
- Glued on nest





Name	Nom X	Nom Y	Nom Z	dX	dY	dZ
TOP1	-147.492	398.167	-522.974	-0.030	0.063	-0.005
TOP3	147.483	398.165	-376.929	-0.011	0.063	-0.007
TOP2	147.490	398.162	-522.959	0.010	0.059	0.010
DS3	199.992	350.199	-305.838	0.038	-0.031	0.029
US4	-200.018	350.179	-594.308	-0.028	-0.035	-0.044
US1	199.988	350.125	-594.298	0.039	-0.002	-0.051
DS2	289.953	-224.875	-305.705	-0.009	-0.021	0.057
DS1	-200.079	-299.718	-305.704	0.024	-0.165	0.049
US2	199.910	-299.946	-594.156	0.019	-0.032	-0.021
US3	-200.089	-299.980	-594.195	-0.052	0.100	-0.017

Name	Nom X	Nom Y	Nom Z	dX	dY	dZ
QC1	-195.718	400.372	3028.828	0.000	-0.003	0.000
QC2	197.498	400.377	3034.412	0.001	-0.002	-0.001
QC3	199.719	400.388	3220.867	-0.001	0.000	-0.001
QC4	293.224	219.213	2976.783	0.003	0.002	0.001
QC5	-258.085	259.221	2977.262	-0.003	0.003	0.001

2. Magnet Center Based on Mechanical Feature (5)

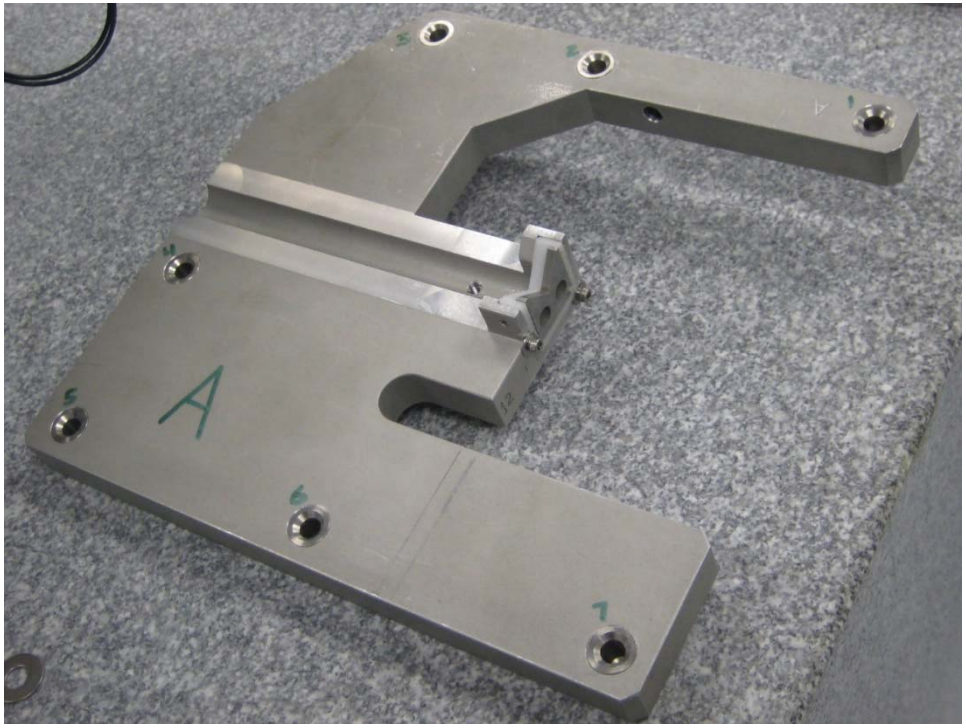
Impact of computation method to magnet center

- Selection of measured points.
- Temperature compensation
- Fiducial location

Fiducial used	Eliminating bad points	Scale free	X	Y	Z
Top	No	Yes	0.011	0.091	-0.187
Top	No	No	0.014	0.119	-0.045
All	Yes	No	0.017	0.079	-0.059
All	No	No	0.030	0.057	-0.053
All	No	Yes	0.025	0.046	-0.051
All	Yes	Yes	0.032	0.020	-0.047
All	Yes	No	0.017	0.079	-0.059

3. Magnetic Center Determined by Vibrating Wire (1)

- The line defining error. The wire center finding process had a combination errors of fiducialization, re-survey and computation which is a similar case to magnet.
- The measurement error of vibrating wire system, which was better than 10 micron.



4. Deviation between Magnetic and Computed Mechanical Center (1)

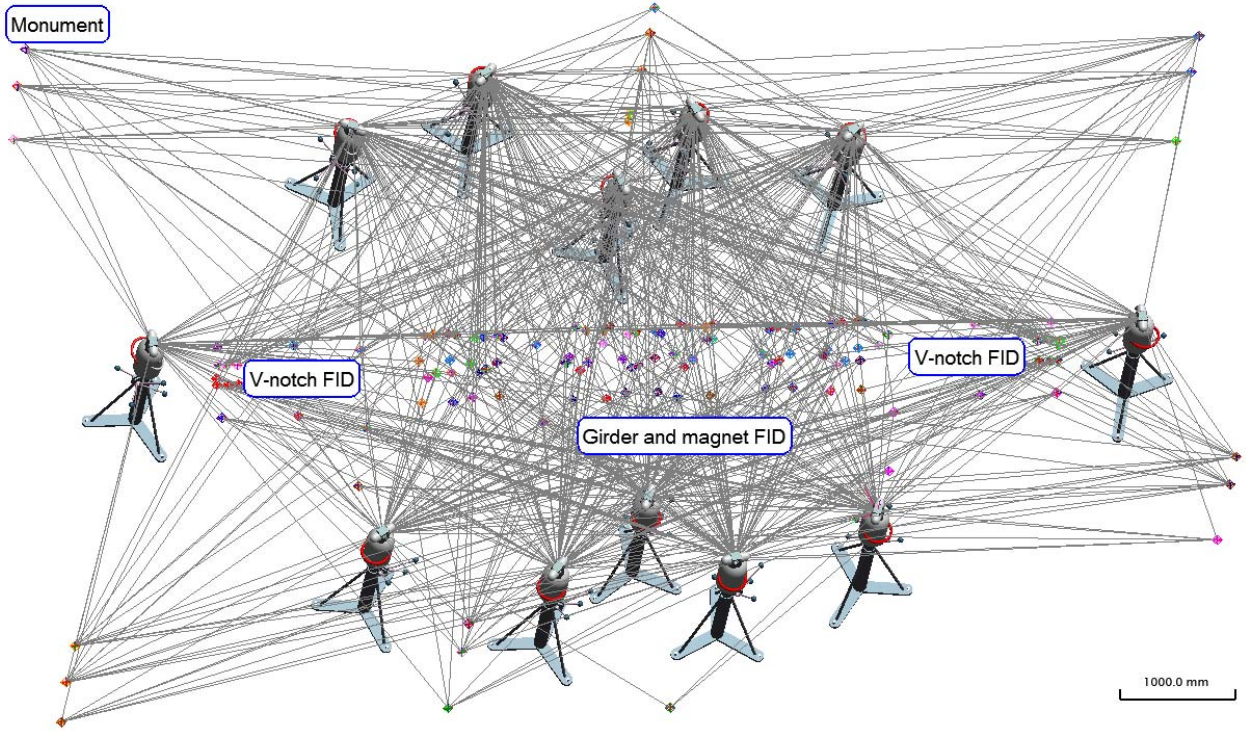
Steps to follow:

- Measure fiducials on V-notches, magnets and girder and monuments around so that all of them has location information in one coordinate system.
- Bring in the fiducial information of V-notches and magnets.
- By performing best-fit transformation the mechanical centers of vibrating wire and magnets can be computed.
- Comparing magnetic center with mechanical center, the deviation can be obtained. Since magnetic center has about 10 micron accuracy, the accuracy of the computed mechanical center can be estimated.

4. Deviation between Magnetic and Computed Mechanical Center (1)

Multiple laser tracker setup

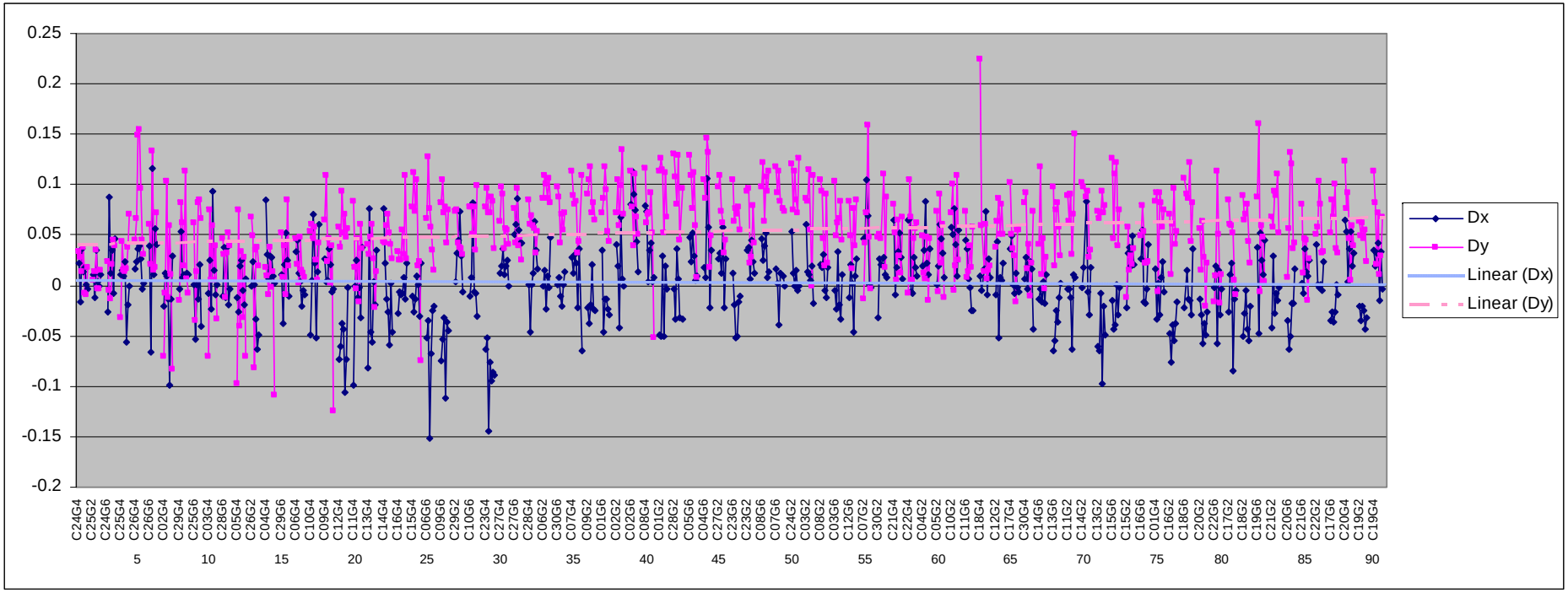
- 12 laser tracker position.
- ~800 points
- ~4 hours



4. Deviation between Magnetic and Computed Mechanical Center (2)

Deviation

- 90 girders.
- Systematically 50 micron in elevation, RMS ~40 micron



4. Deviation between Magnetic and Computed Mechanical Center (3)

Laser tracker resolution test

- For one girder, one quadrupole was left misaligned intentionally with the offset of (0.066, 0.125) mm as indicated by vibrating wire.
- • By performing a complete 12-tracker setup before magnet alignment, the relationship between the object magnet and adjacent magnets was precisely established. This is a simulation of fiducialization as the relationship between fiducials and magnetic center of the magnet was established according vibrating wire data after laser tracker measurement.
- • 2 laser trackers were used to align the magnet by referring to the magnet fiducials.
- • 6-tracker setup was used to capture the as-built information. It showed an offset of (0.0023, 0.0094) mm.
- • As a last step, vibrating wire was used to measure the location of the quad. It showed an offset of (-0.001, 0.012) mm.
- • Comparing the data together, the deviation between laser tracker and vibrating wire is only (-0.003, 0.003) mm.

Summary

- The magnets on common girder were precisely aligned by vibrating wire with very high precision achieved. The precisely aligned magnets provide accurate magnetic centers.
- The magnets were fiducialized by articulated arm by measuring the pole tips and fiducials. Since the fiducialization of magnets is just for rough alignment purpose, fiducial holes with bad repeatability were used and the temperature was loosely controlled when measurement was performed.
- By comparing the magnetic and mechanical center deviation, a deviation of ~40 micron (RMS) is found. The factors described above contribute a lot.
- It's not uncommon that similar setting of fiducials and measurement method is used in other facilities. Therefore, the result here can give a good estimate regarding the fiducial precision of mechanical method.
- To improve, good fiducials, controlled environment and precision measurement should be a minimum.

Acknowledgement

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Thanks for your attention!

Questions?