National Synchrotron Radiation Research Center

Using an in-situ field measurement system to measure the magnetic field of in-vacuum undulators

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IMMW18

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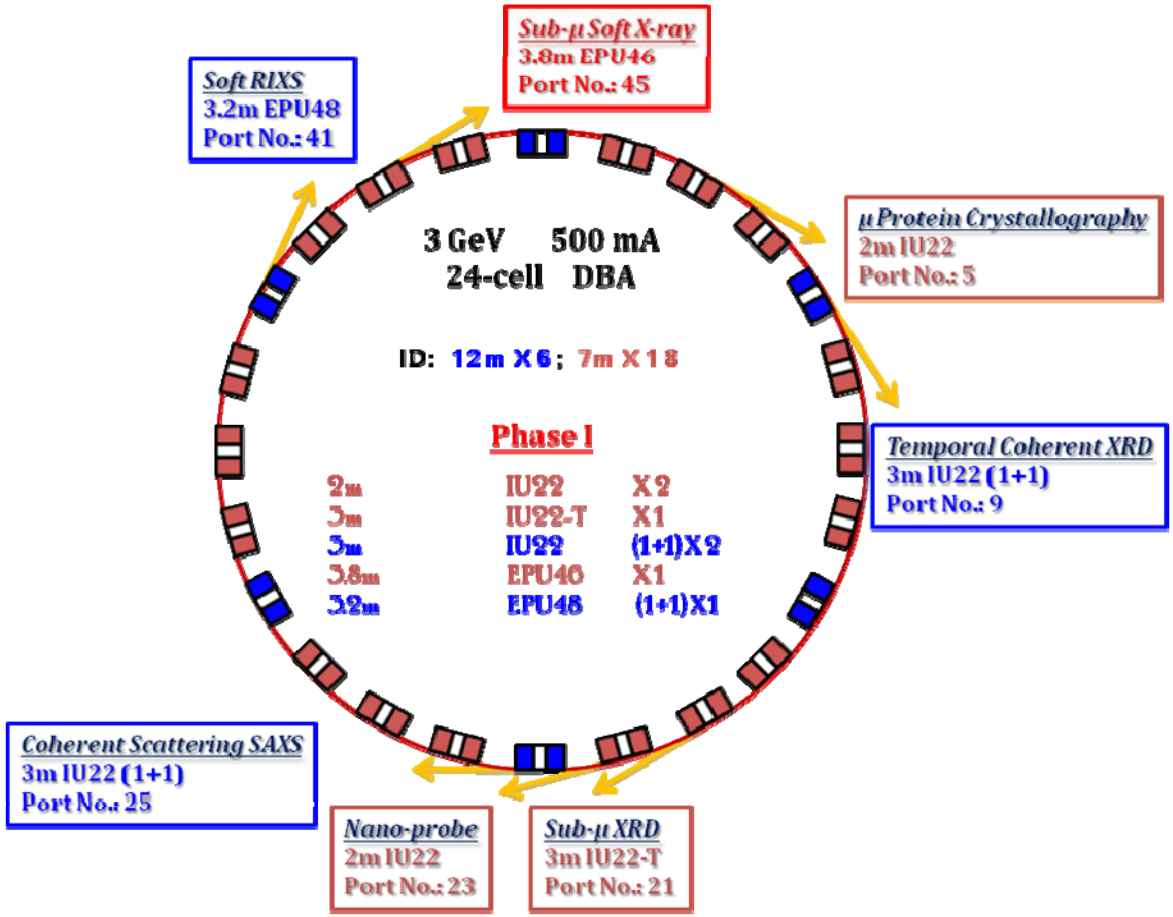
TPS Beam-line Plan

- TPS (Taiwan Photon Source) consists of 24 straight sections, including eighteen sections of length 7 m and six sections of length 12 m, to accommodate beam-injection devices, a SRF cavity, insertion devices and so on.
- In the initial commissioning stage of TPS (Phase I), ten insertion devices will be installed to serve seven beam-lines. Seven of them are in-vacuum undulators.



IU22-2m

- **Two sets of IU22-2m are manufactured by Hitachi Metal, NEOMAX.**
- **The ultimate vacuum pressure requires to be below $3x10^{-8}$ Pascal.**
- **A Bake-out system with hot pressurized water will be used to do bake-out process.**
- **The Magnetic performance was measured before assembling the vacuum chamber.**

Items	Requirements
Magnetic circuit	
Periodic length	22 mm
No. of Period	≧ 90
Magnetic length of the device	1.98m
Gap range	7 ~ 50 mm
Effective field at 7mm Gap	>0.72T
Magnet (Pole) material	NdFeB (Permendur)
Magnetic Field homogeneity	
Good field region $\triangle B/B$ smaller than $7x10^{-3}$	@ x_ axis >±15.0 mm
Maximum RMS Phase error at all gap (7~50mm)	<3.0°
Limits for the vertical and horizontal integrals on-axis in the full gap	
--First integral with steering corrector	≦ 30 Gauss-cm
--First integral without steering corrector	≦ 100 Gauss-cm
--Second integral with steering corrector	≦ 2000 Gauss-cm^2
--Second integral without steering corrector	≦ 35000 Gauss-cm^2

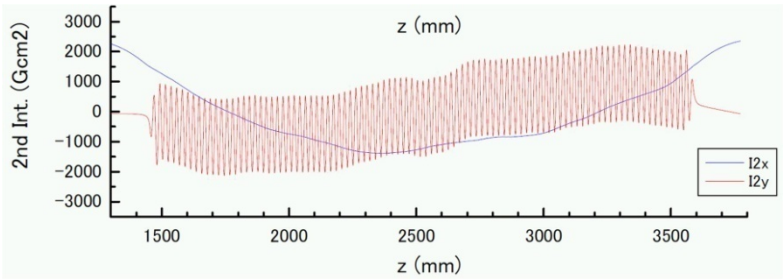
Phase error

Gap(mm)		5	7
P.E.(deg.)	N1	1.2	1.2
	N2	1.6	1.5
	Spec.	≦3	
Results		OK	

Peak By

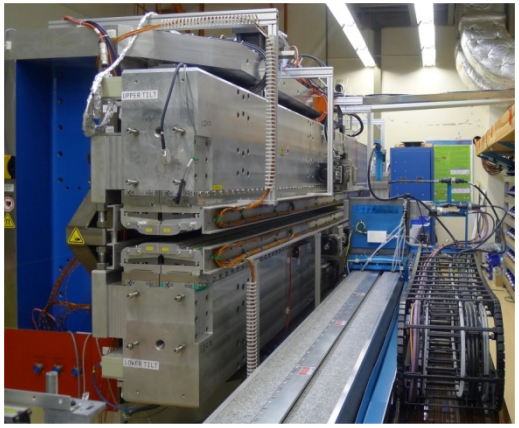
Gap(mm)		5	7
By(T)	N1	1.09	0.74
	N2	1.07	0.73
Spec.		1.01	0.72
Results		OK	

2nd integral at gap 7mm

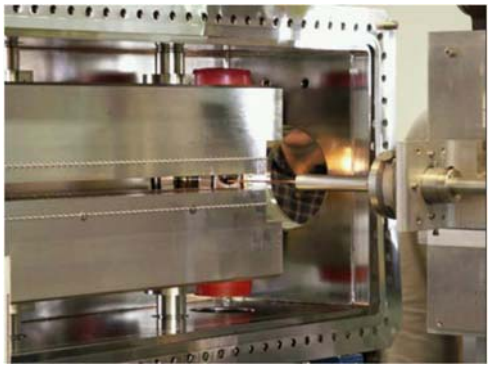


Re-check challenge

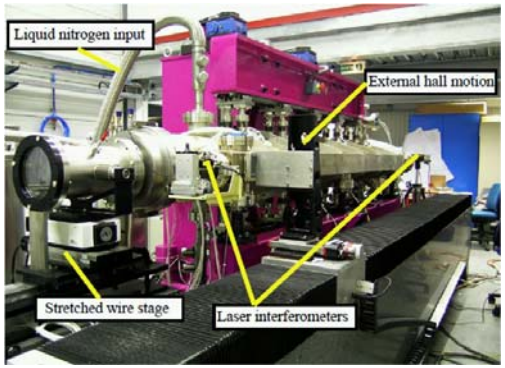
Due to the vacuum chamber, the granite-based field measurement system can't be used.



NSLS



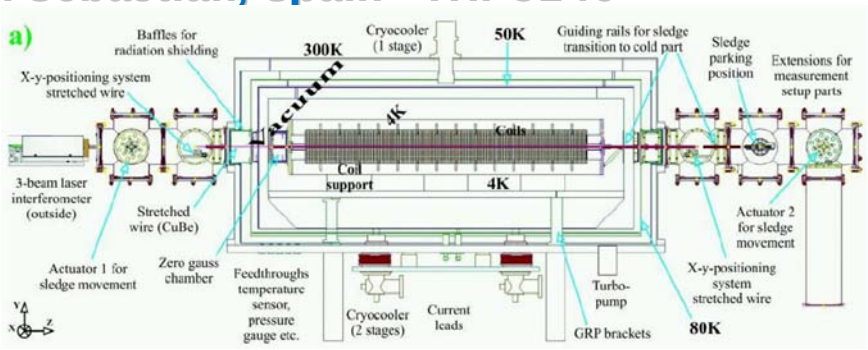
ESRF



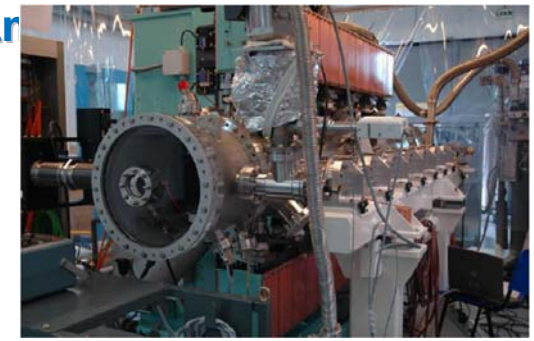
Solutions :

- **NSLS -> 2006 *AIP Conf. Proc.* 879, 283-286**
- **ESRF -> Proceedings of EPAC08, Genoa, Italy WEPC105**
- **ANKA -> Proceedings of IPAC2012, New Orleans, Louisiana, USA MOPPP067**
- **SOLEIL -> Proceedings of IPAC2011, San Sebastián, Spain THPC149**
- **ALBA ar**

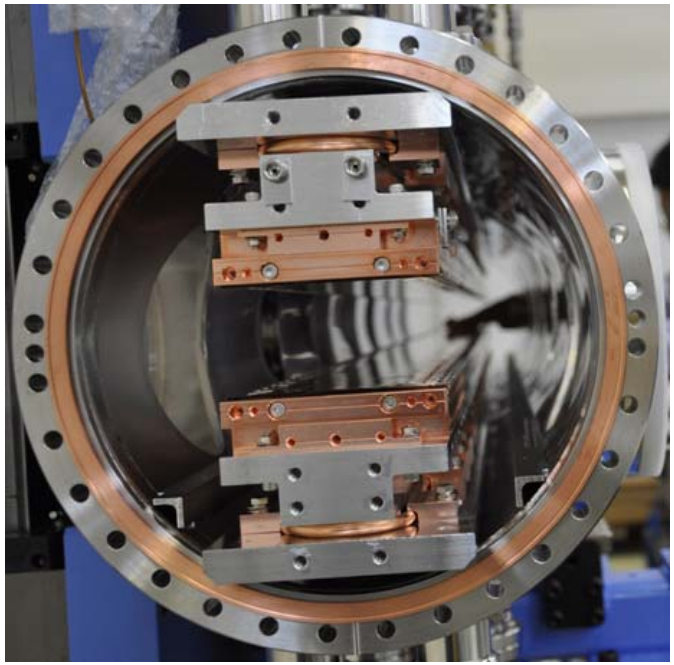
ANKA

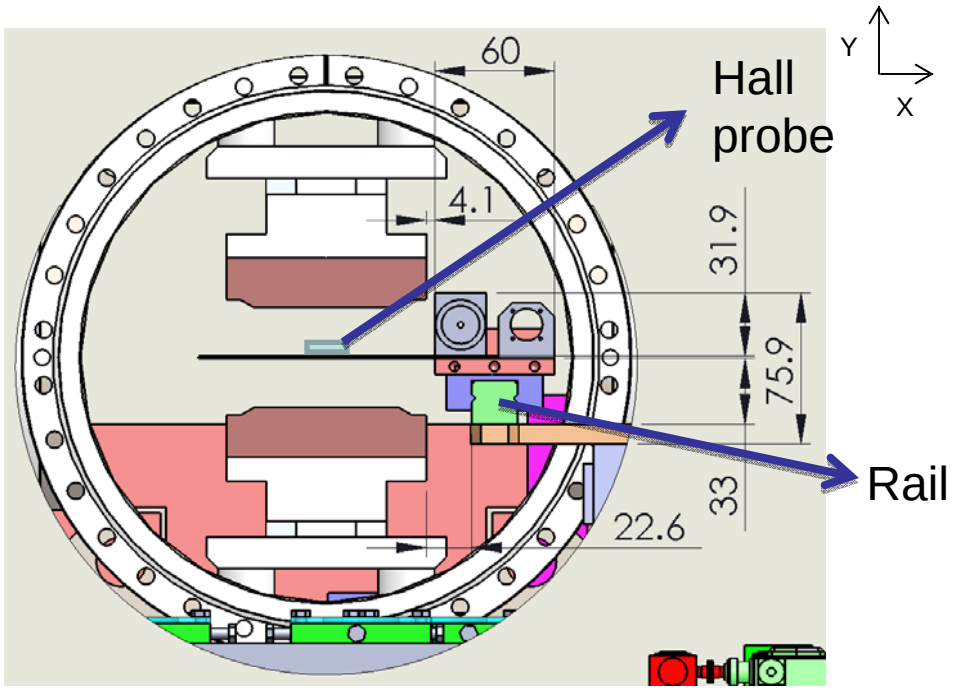


SOLEIL



Design concept



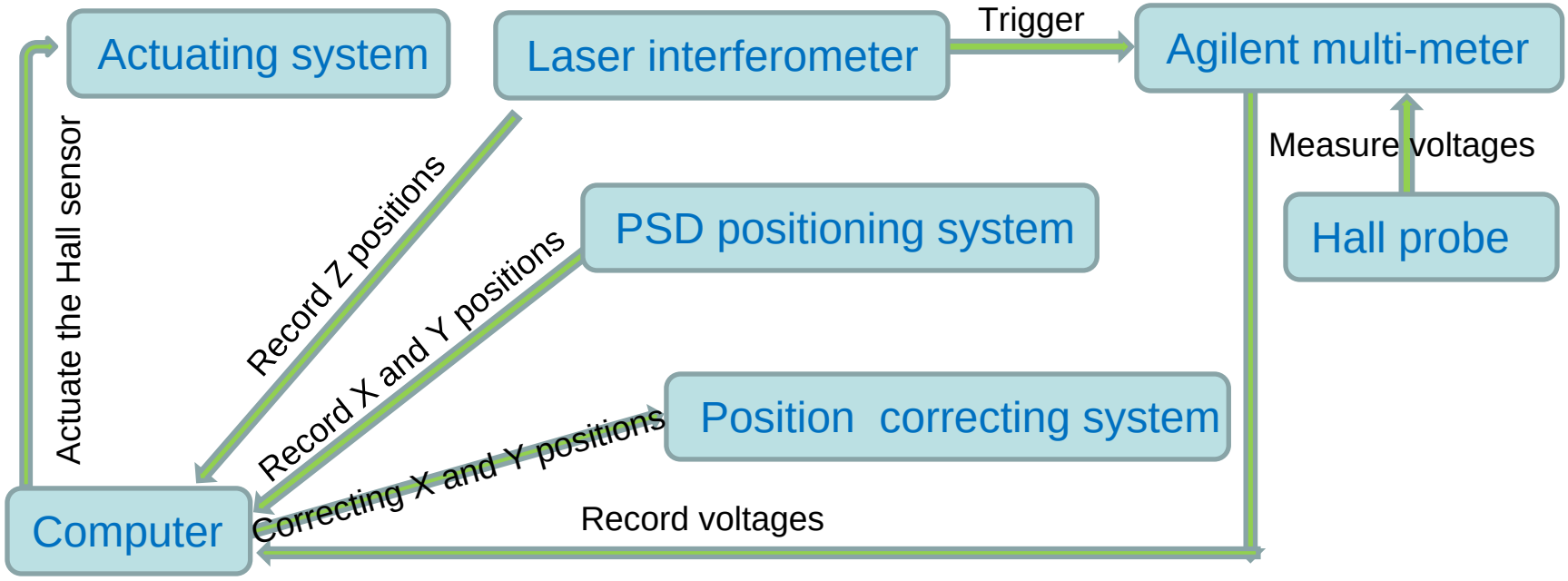


- The available space is about eighty mm in height and sixty mm in width.
- A Hall probe is attached on a ceramic plate.
- The ceramic plate, a pinhole, and a corner cube are fixed on a carriage.
- The carriage is mounted on a rail and moves along z axis.
- Measurement control and data analyses are done by Labview.

Description of the system

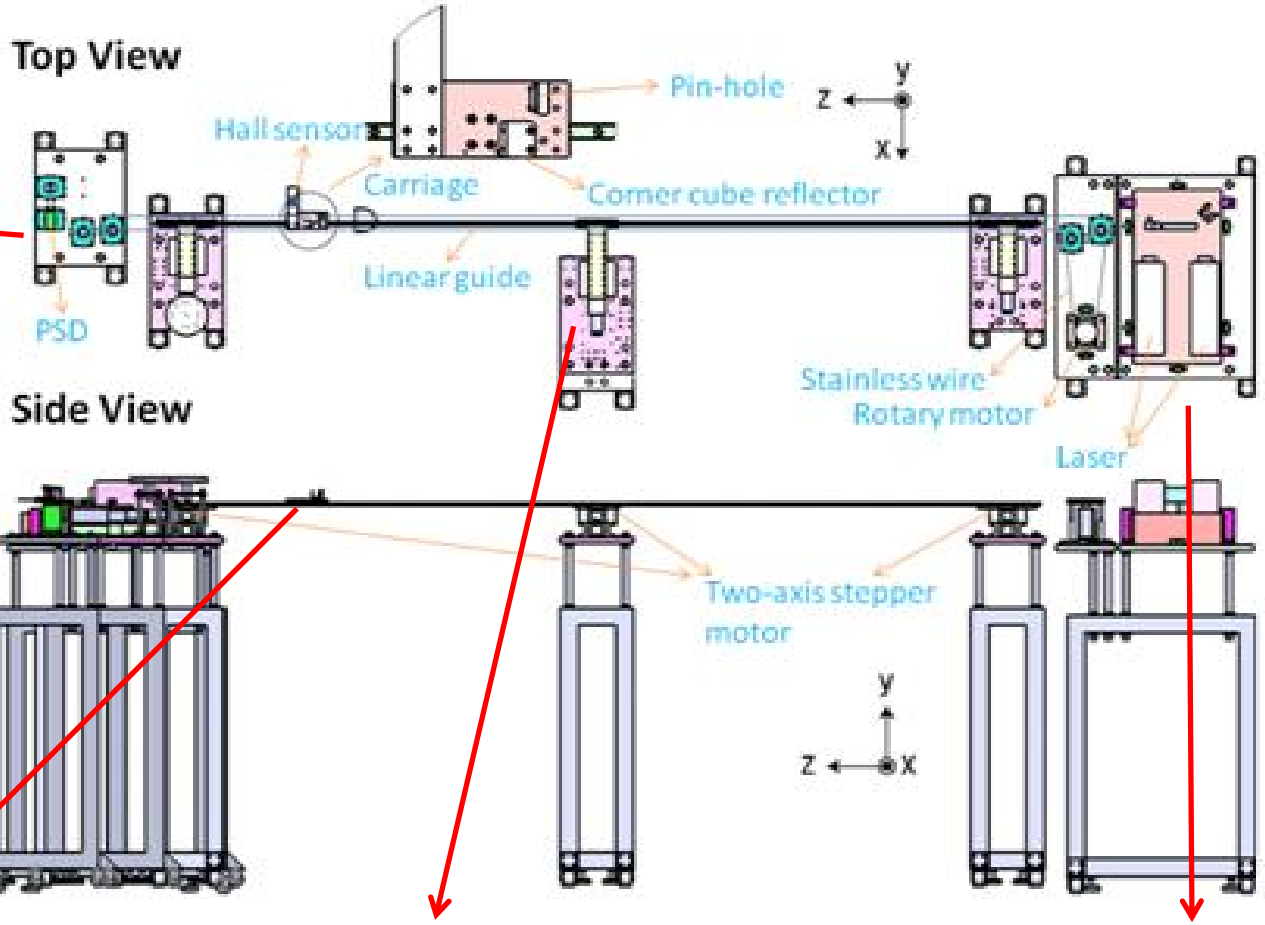
This system consists of three sub-systems :

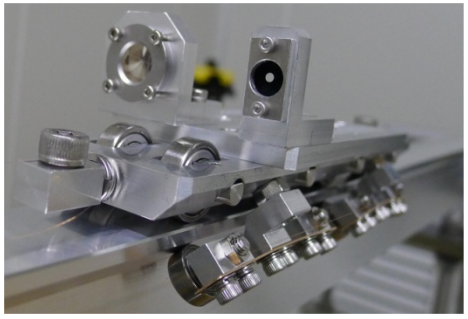
1. Hall probe actuating system – Move the Hall probe along longitudinal (Z) axis.
2. Hall probe positioning system –
   - Laser interferometer - Monitor the Hall probe positions of Z axis.
   - PSD positioning system - Monitor the Hall probe positions of horizontal (X) and vertical (Y) axes.
3. Position correcting system – Correct the Hall probe positions in X and Y axes.

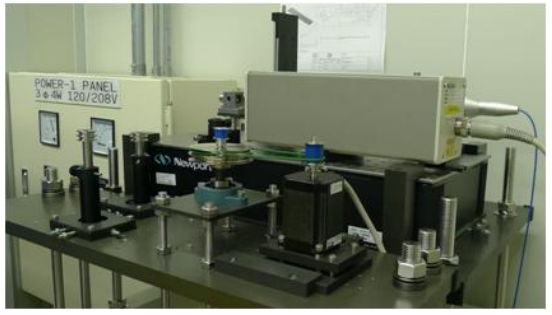


Mechanical Design Diagram

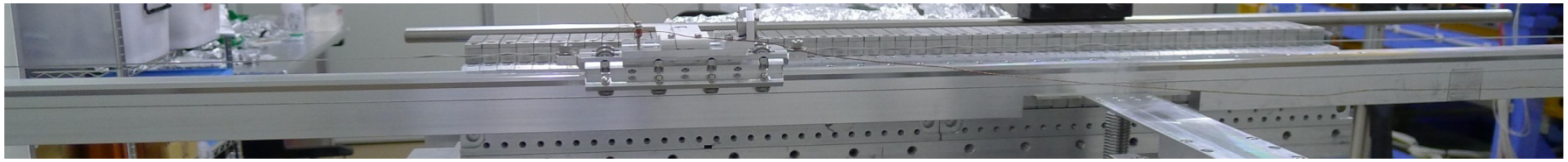
Iron frame

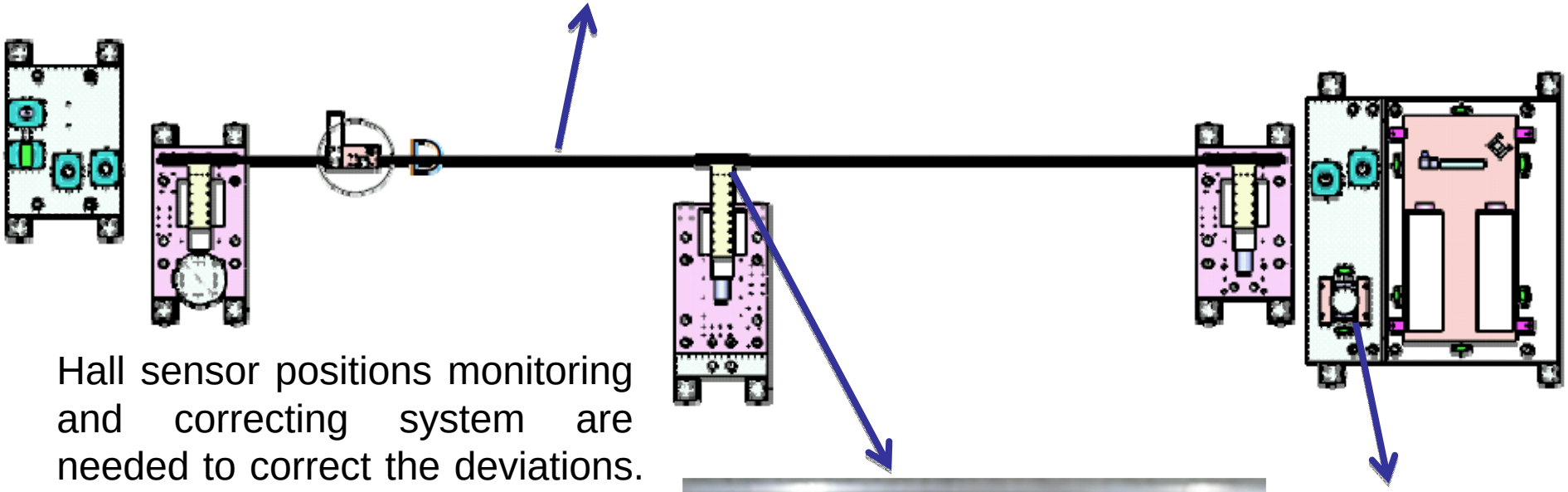




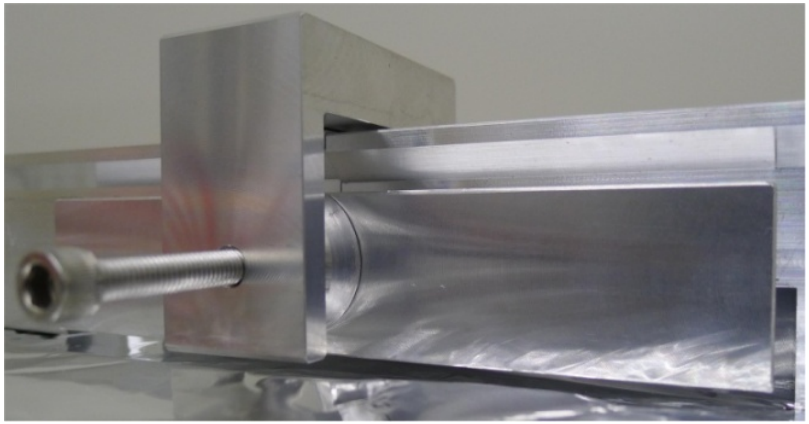


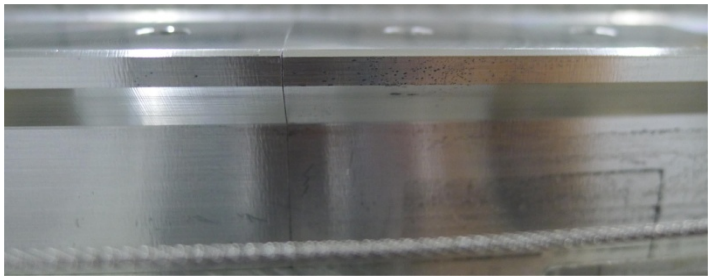
Hall sensor actuation system

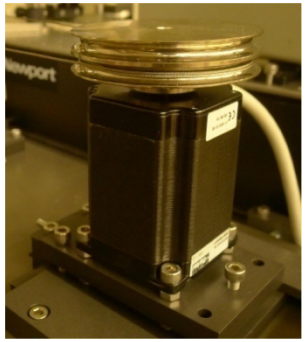




Hall sensor positions monitoring and correcting system are needed to correct the deviations.

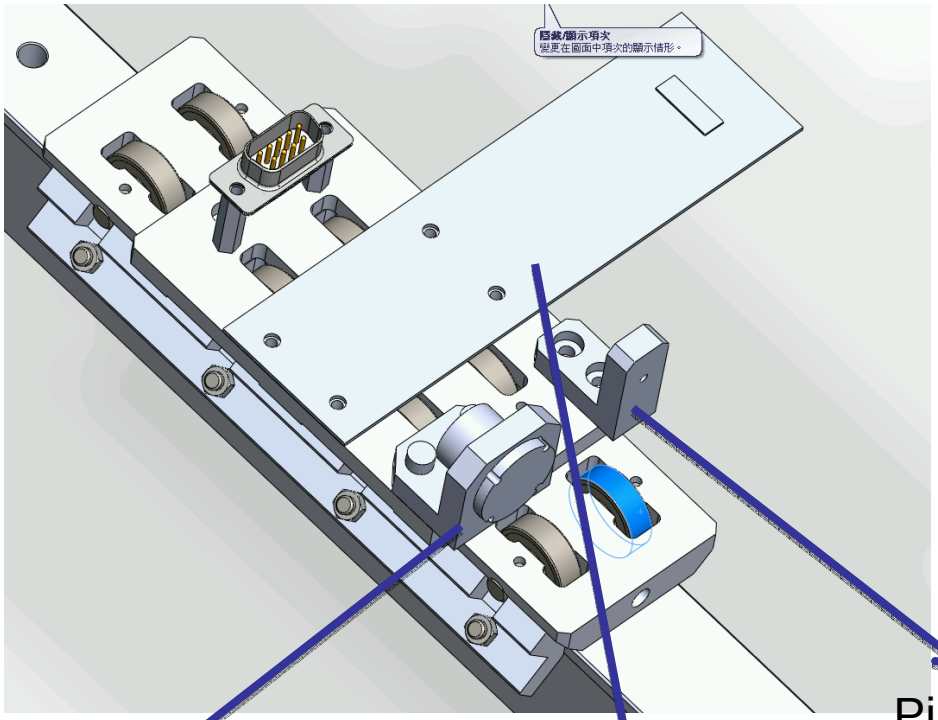


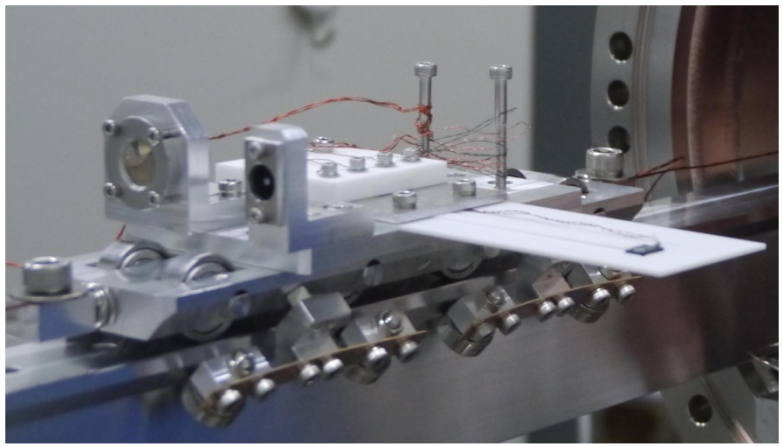




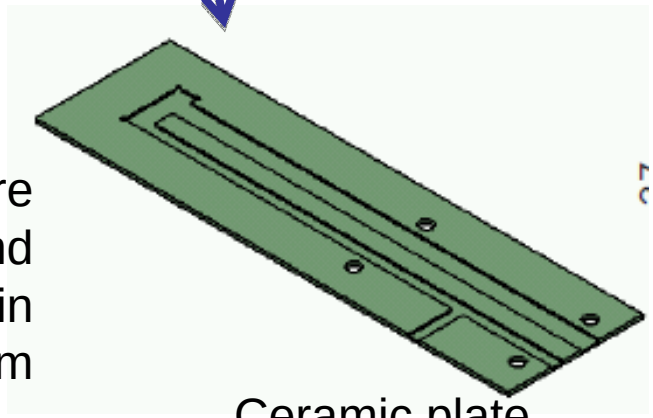
Rotary motor

Carriage and rail



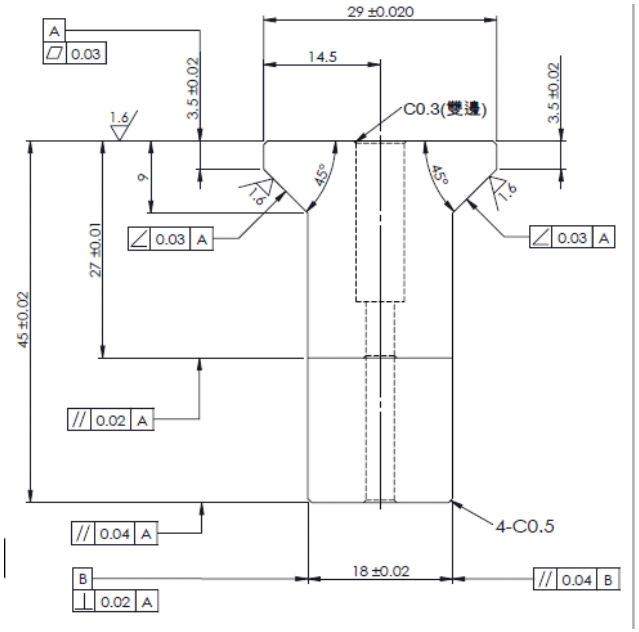


Rail

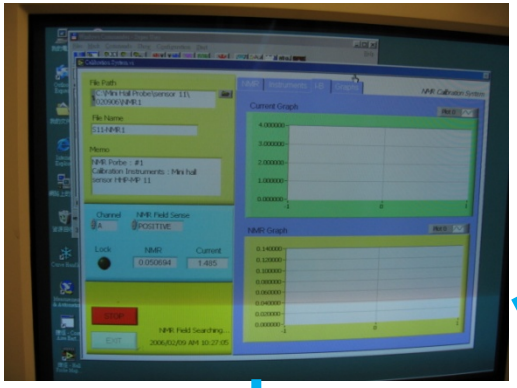


Ceramic plate

All components are non-magnetic and compatible used in high vacuum enviroment.



Hall sensor calibration system



Hall probe : Arepoc HHP-MP

Magnetic field uniformity : 0.4G/6cm
Apply current : 0~± 40 A
Five NMR probes : | B | =0.04~2.1T
Two ESR probes : | B | =5.5~32G
Air gap of magnet : 4.5mm

Record Hall sensor voltages

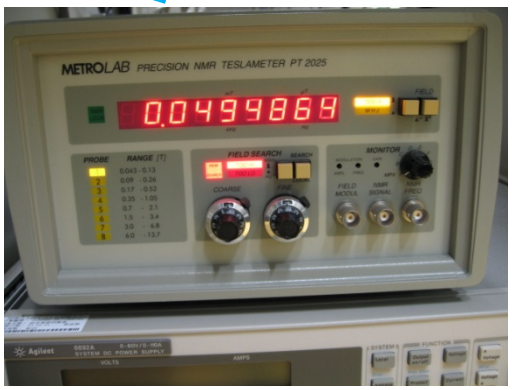
Record NMR readings

Labview software

Control a power supply

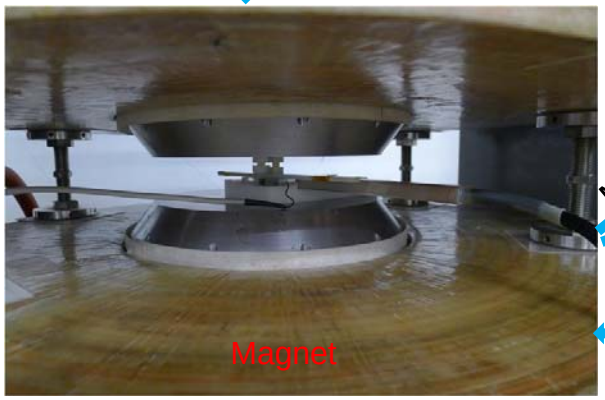
Agilent Power supply

Provide current for magnet



METRO-Lab Precision NMR Tesla-meter (PT2025)

Agilent 411A multi-meter



Magnet

Measure NMR

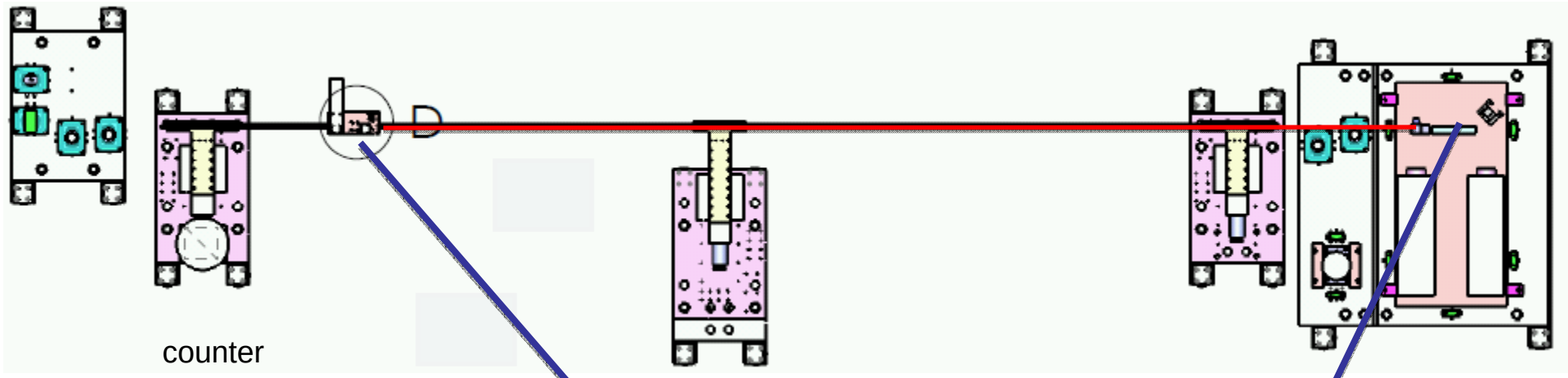
Measure Hall sensor voltages

Provide current for Hall sensor

Lake Shore 120 current source

Laser interferometer

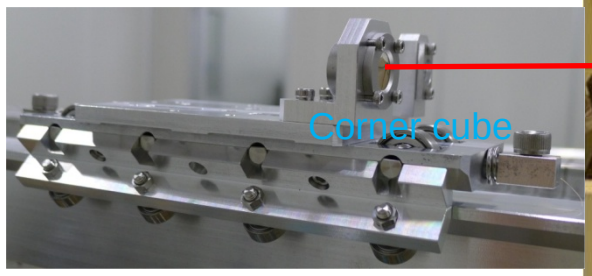
Monitor the longitudinal axis positions and send trigger signals to a multi-meter in a determined interval.



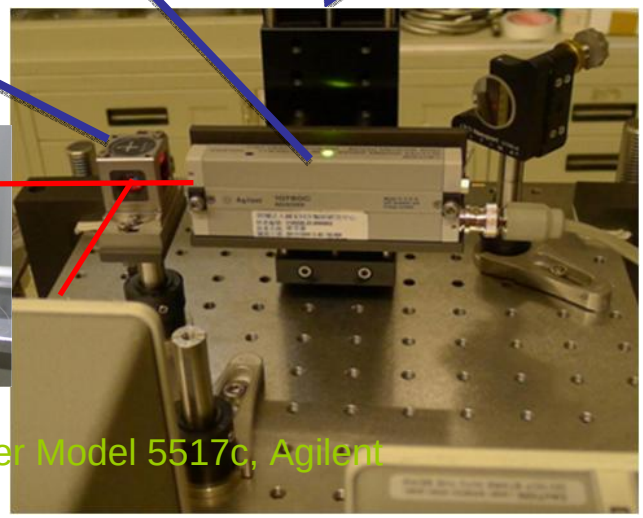
counter

Interferometer

Laser receiver



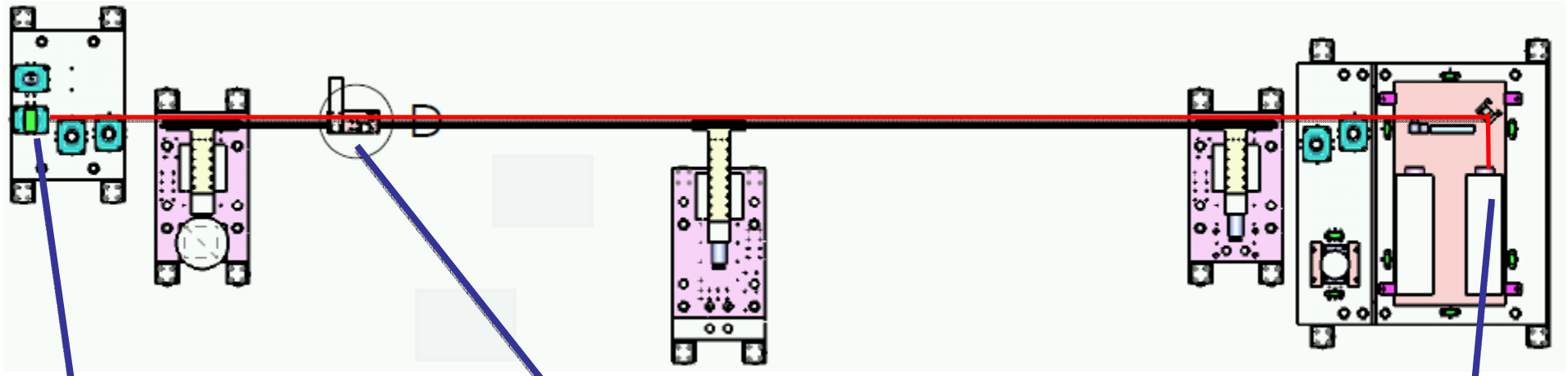
Corner cube

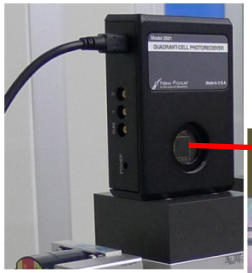


Laser Model 5517c, Agilent

PSD positioning system

Monitor the X and Y positions of the Hall probe.

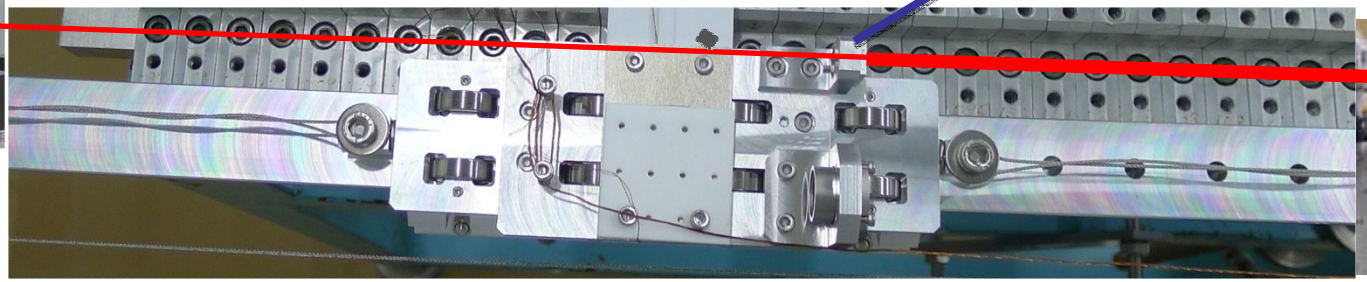




Position Sensitive Device

Pinhole

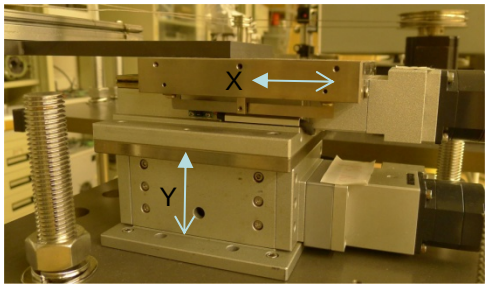
Laser

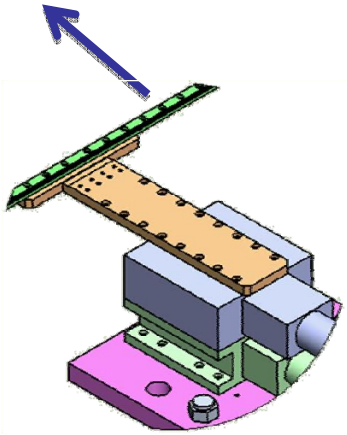


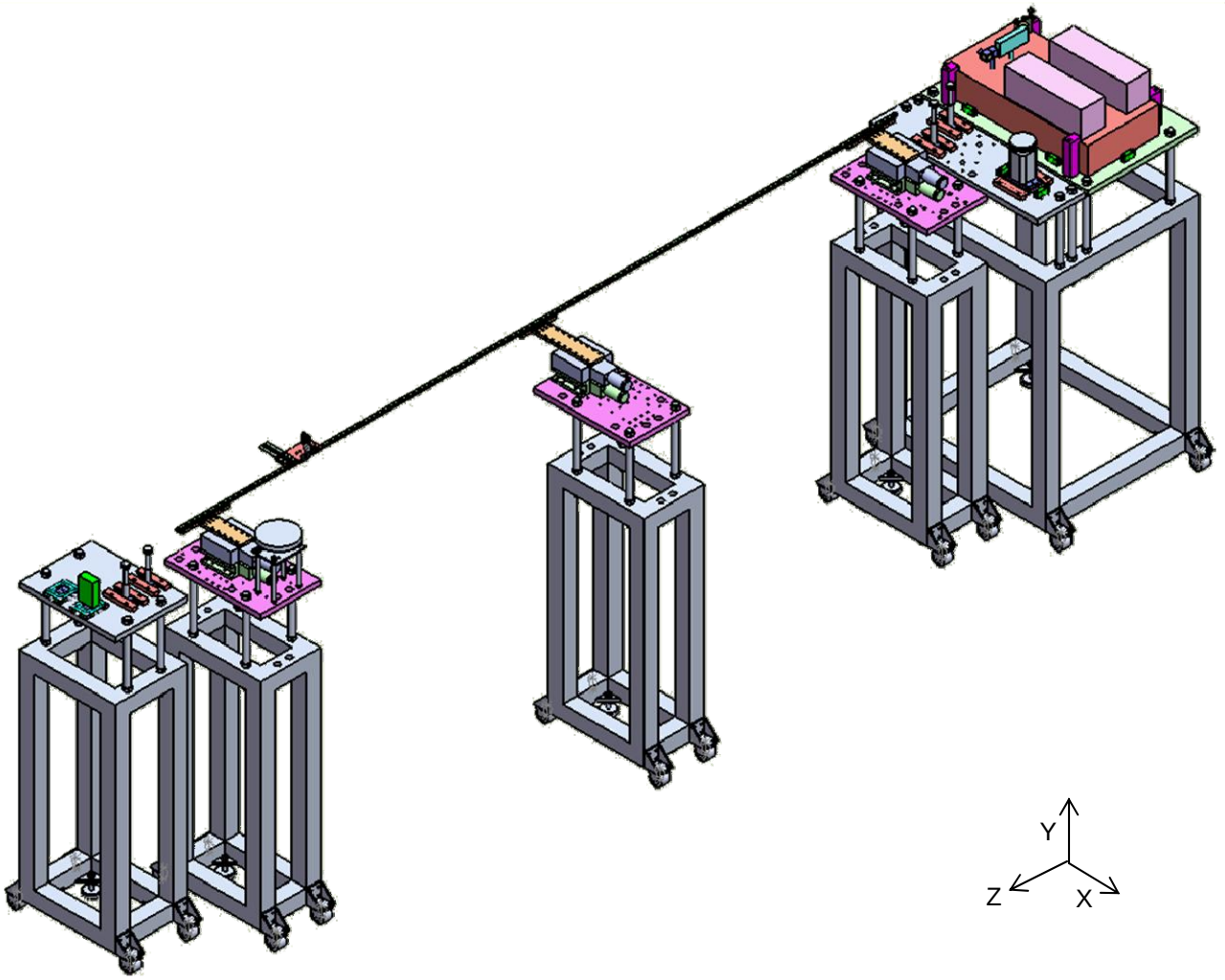
Position correcting system

Correcting the X and Y axes positions

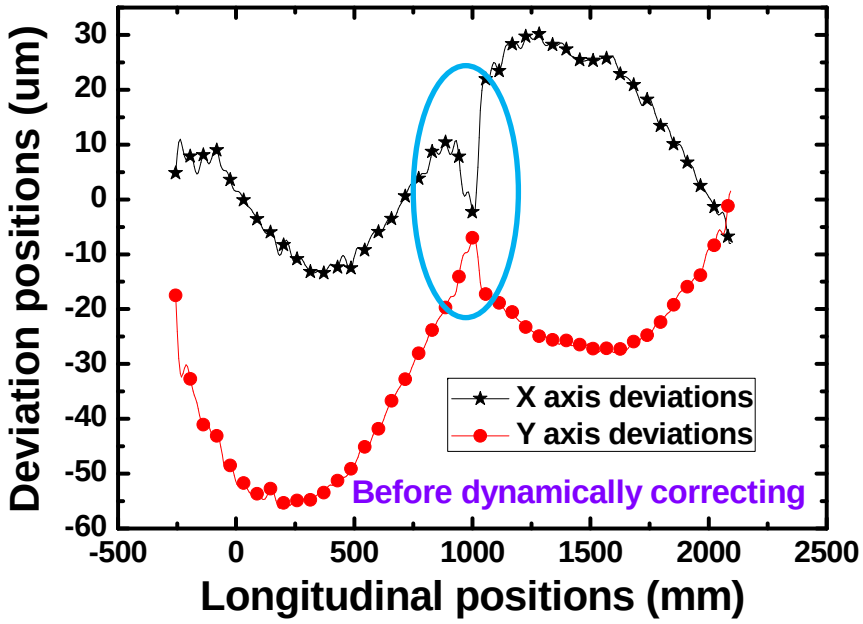
Motor movement resolution :
1 μm in x axis
0.5 μm in y axis

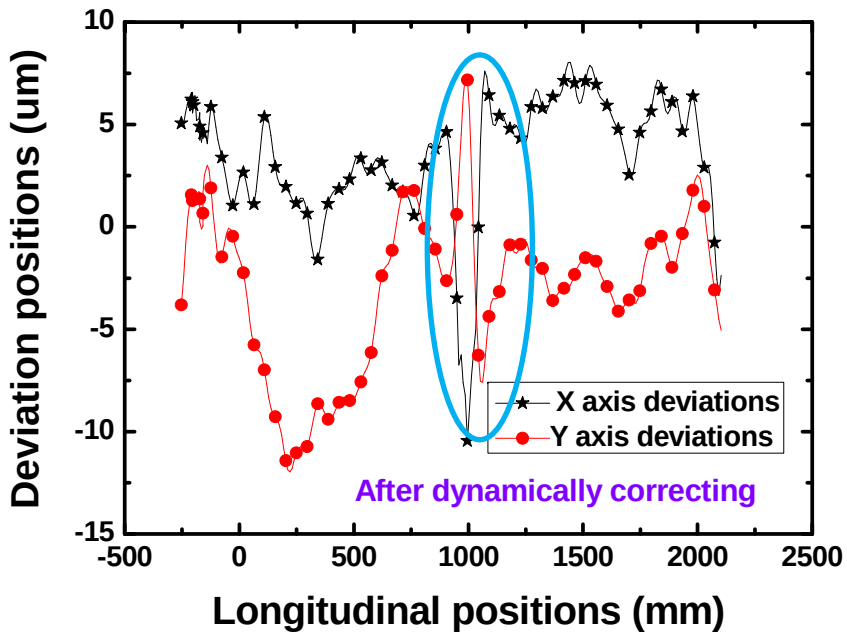






Hall sensor position correction



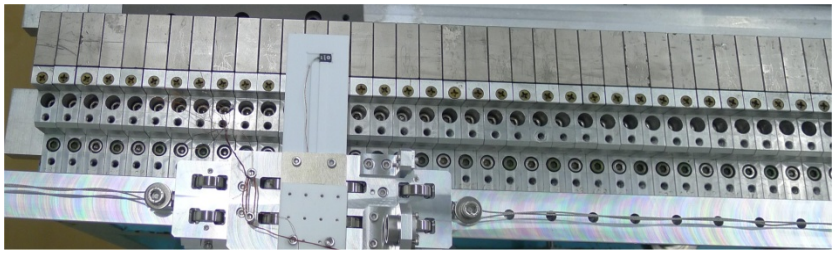


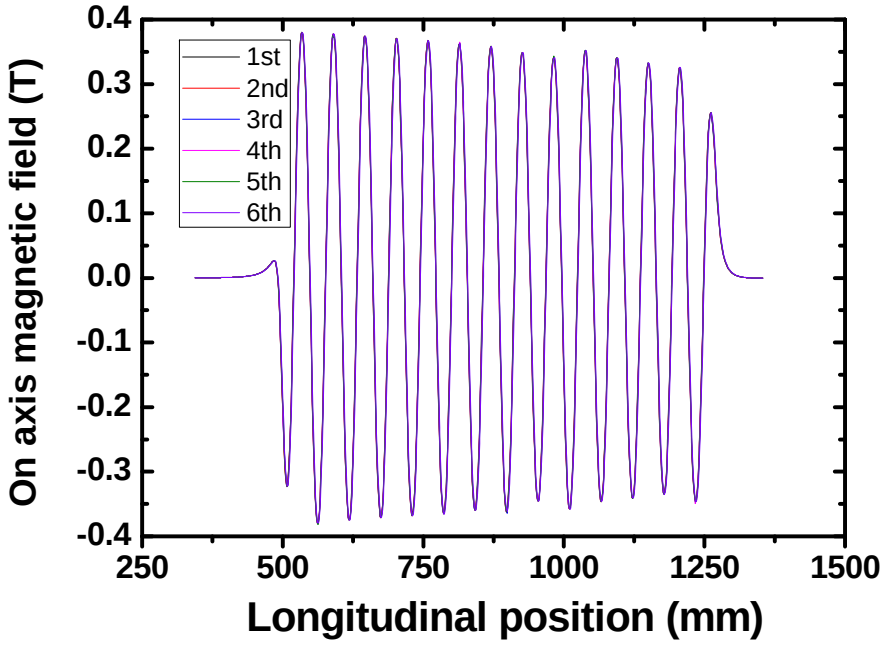
- Position deviations of the Hall sensor are measured along the longitudinal direction.
- Before dynamically correcting, RMS values of position deviations are 15.7 μm in direction *x* and 30 μm in direction *y*.
- After dynamically correcting, RMS values of position deviations are 4.7 μm of both *x* and *y* axes.
- There is a step between two rails. Even with dynamical correction, this step is not easy to be reduced.

System test results

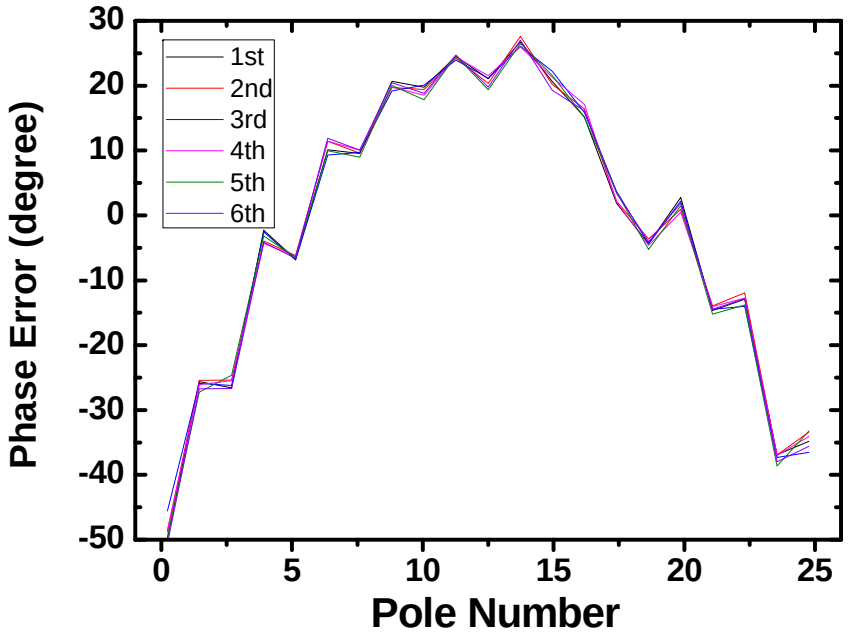
Measure a test array six times in the same condition.

Moving speed : V=1 mm/s
Measuring interval : 0.5mm



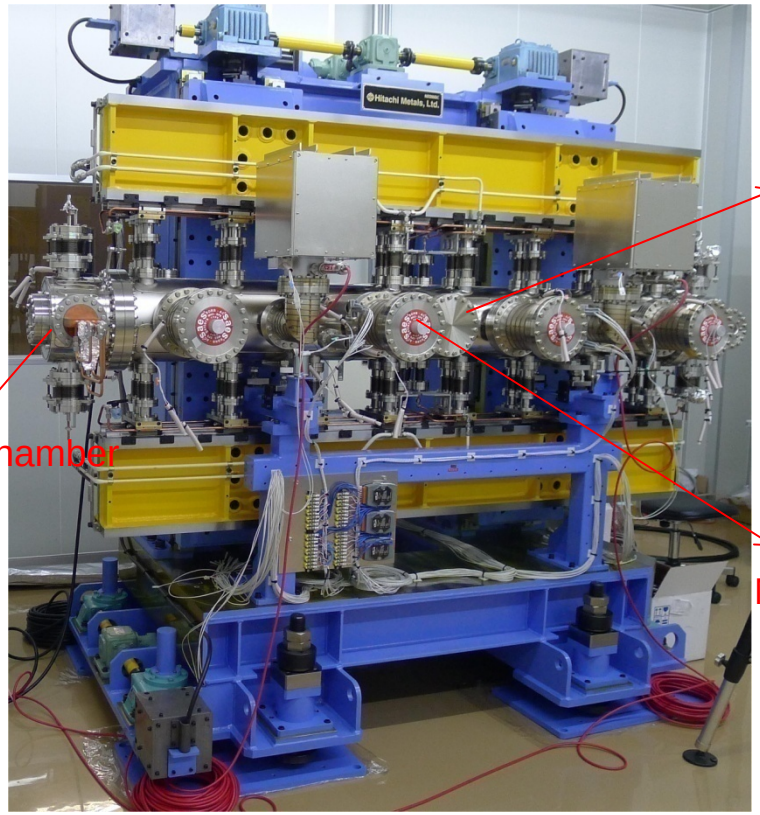


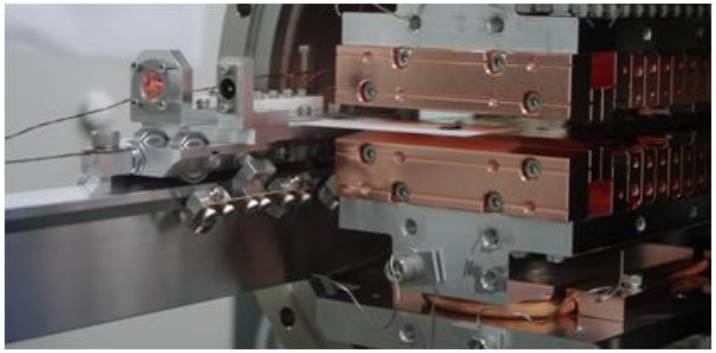
dB_{peak}/B 0.03%



STD of Phase error RMS=0.15 degree

Installed in IU22-2m



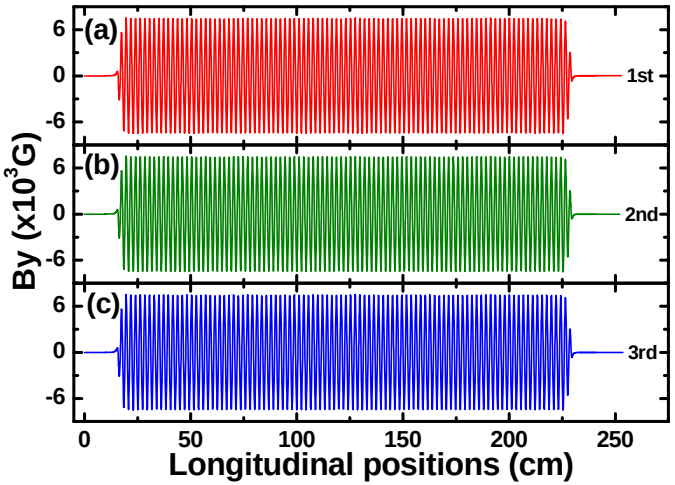


End chambers are removed and the view port should be open. The four NEG pumps are also removed to make the alignment easier.

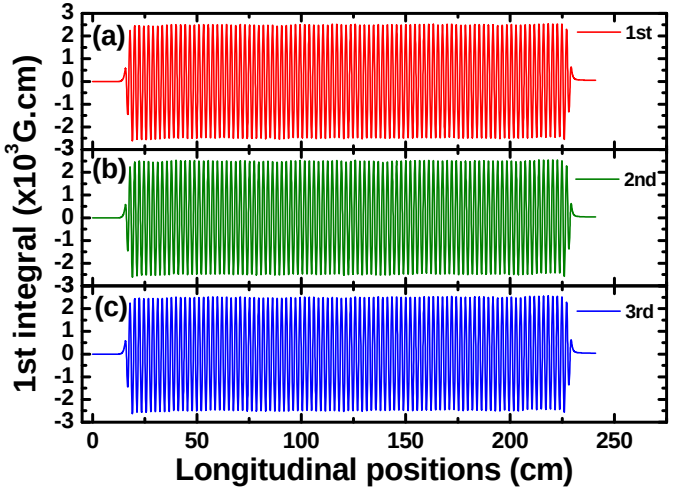
It takes about 3 days to set up the system and align the laser beams.

Reproducibility test

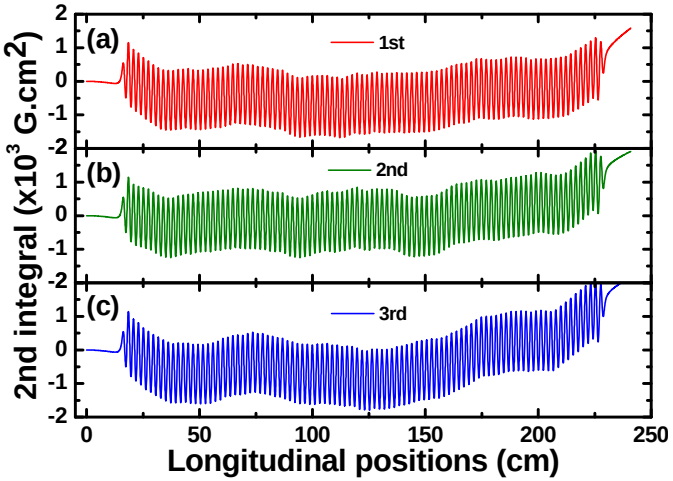
dB/B ~0.03%



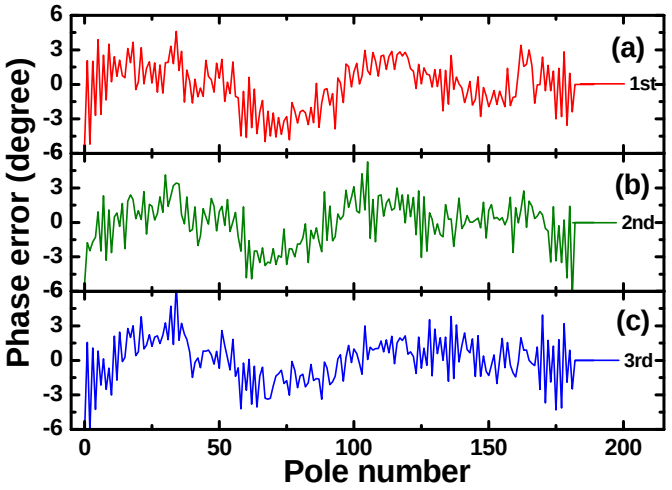
1st integral ~13 G.cm



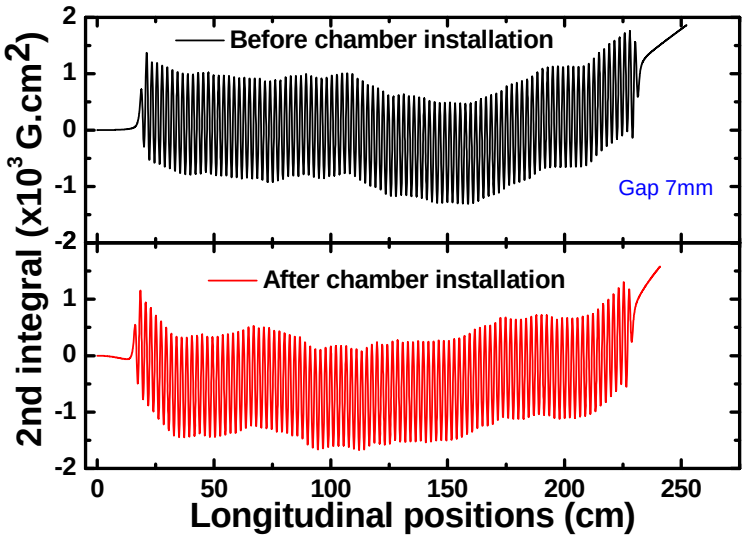
2nd integral ~807 G.cm^2

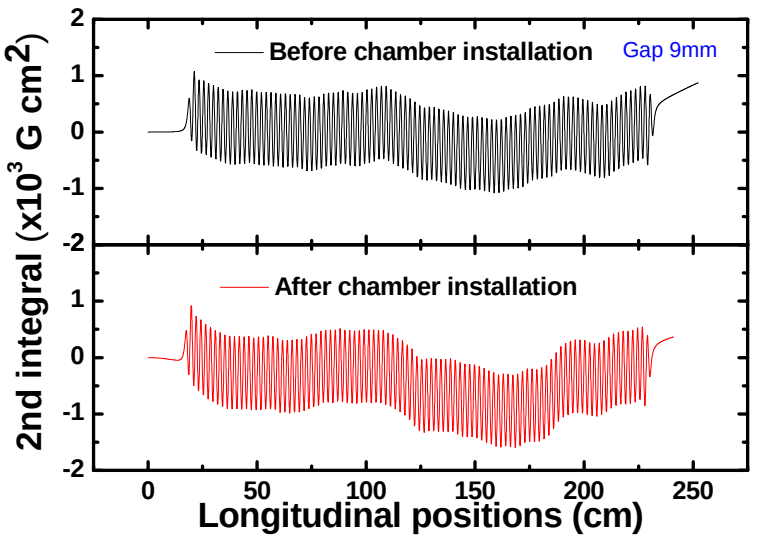


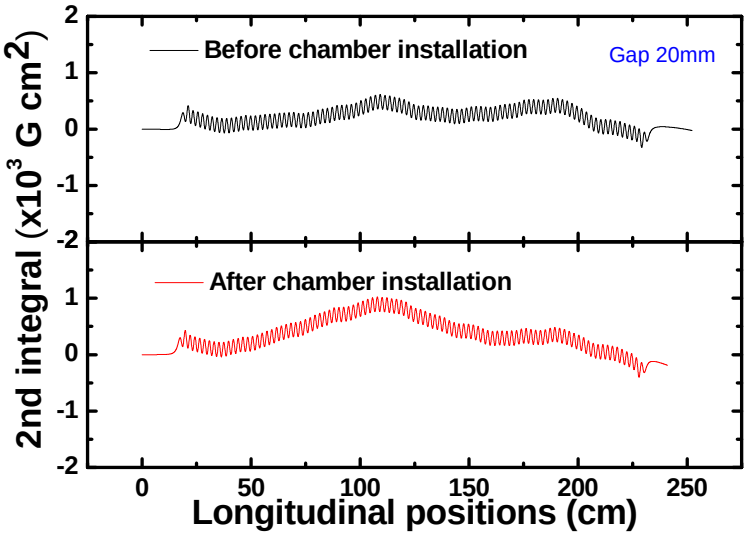
Phase error ~0.15 deg.

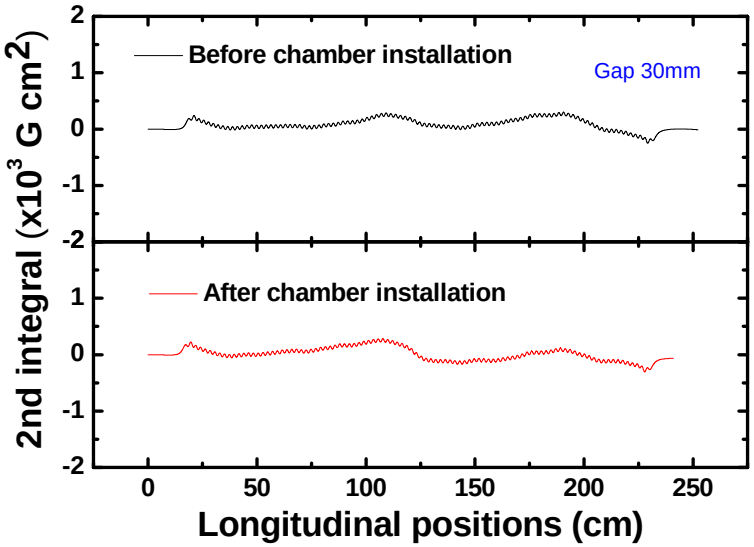


2nd integral results



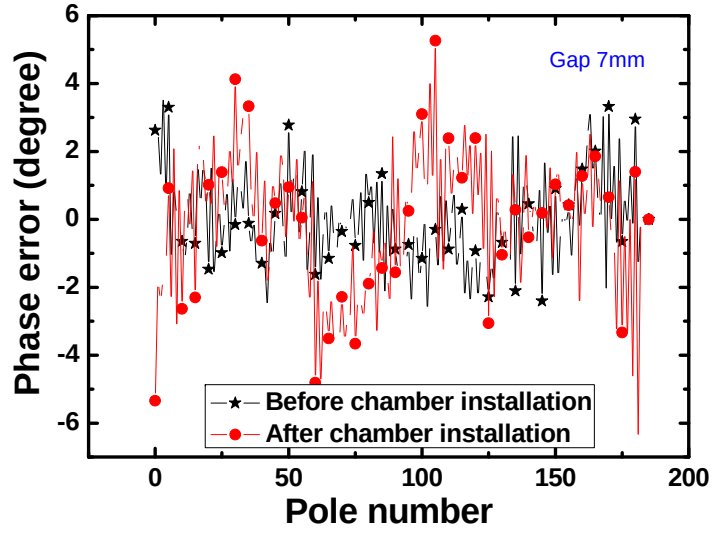


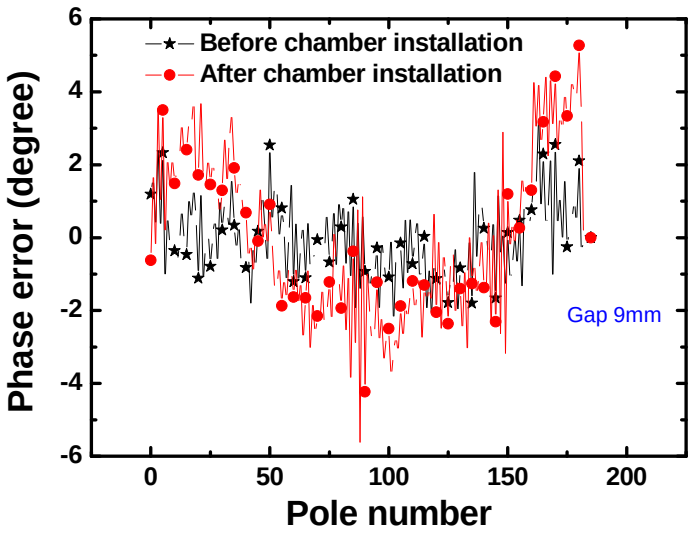


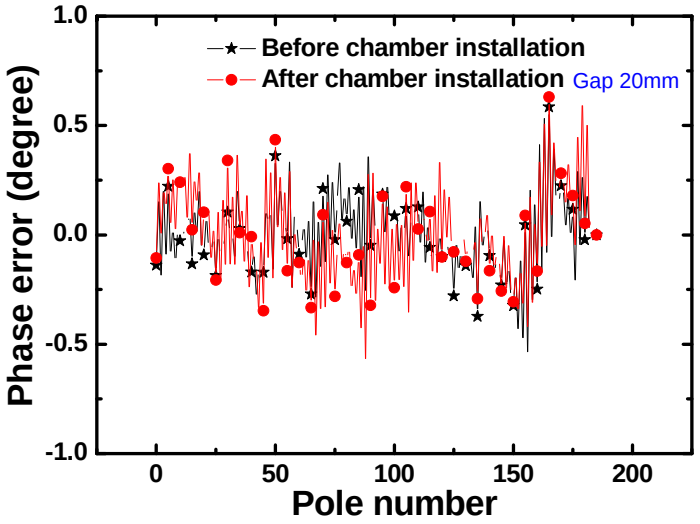


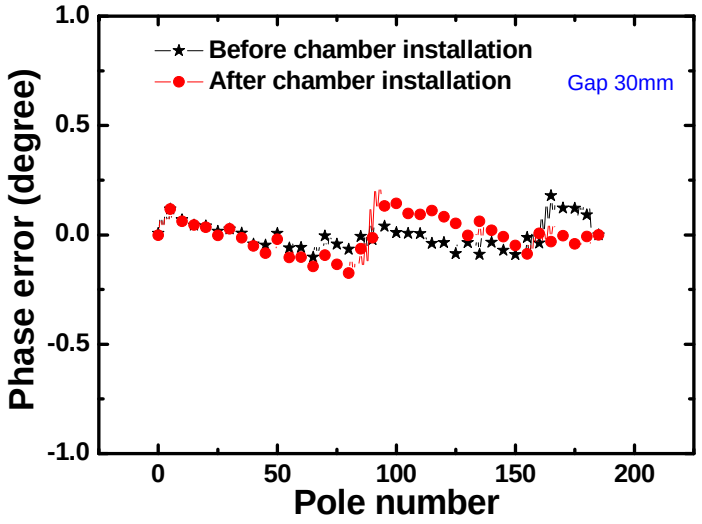
The specification of 2nd integral variation is less than ±2000 G.cm². The checking results show that the performance of two IU22 meet our specifications.

Phase error results







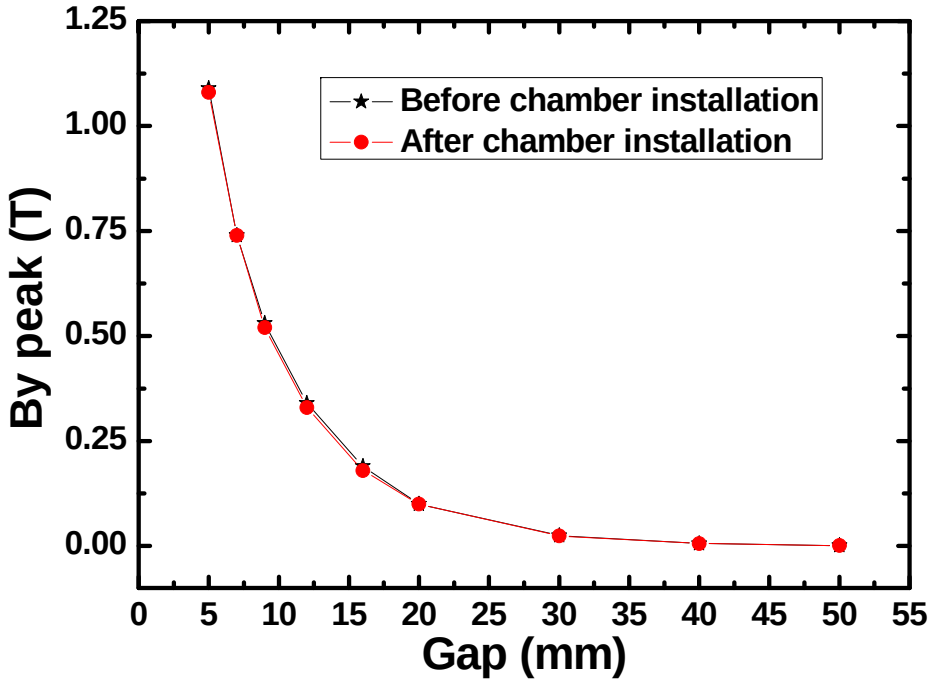


The specifications of phase error r.m.s values are less than 3 degrees at all gaps.

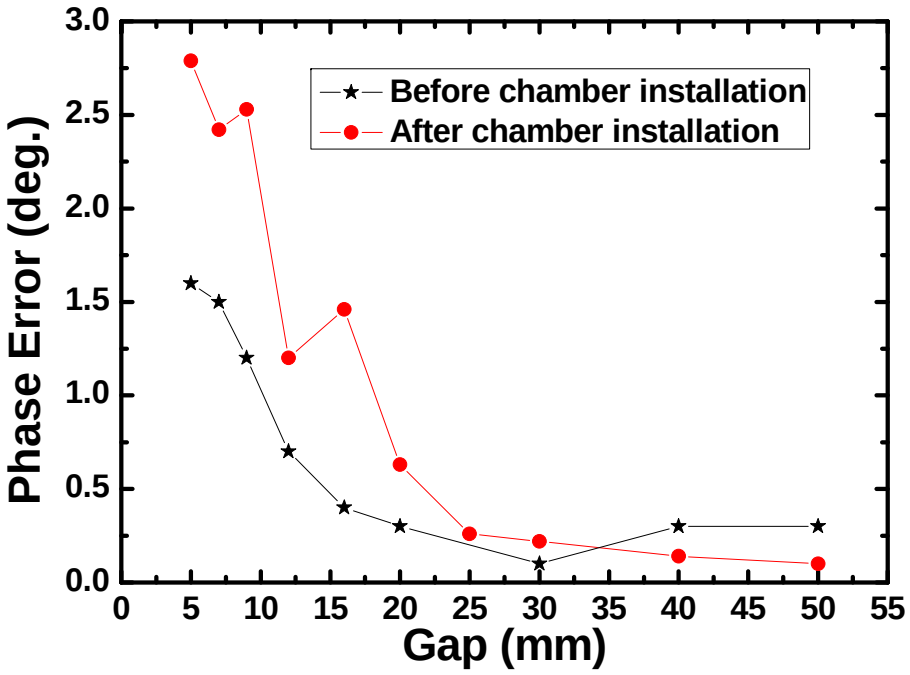
The phase error differences may result from the magnet array gap offset and

Measurement results comparison

Peak fields at different gaps



Phase error at different gaps



- **Peak fields have negligible changes.**
- **After chamber installation, the R.M.S values of phase error at different gaps become a little worse, but they are still satisfied with our specifications, less than 3 degrees.**

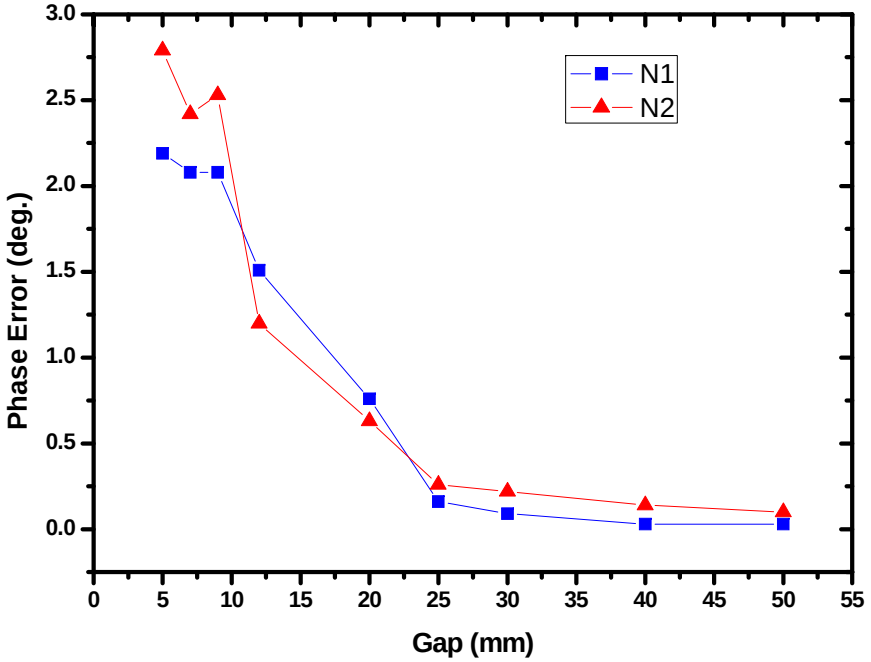
IU22-2m measurement results

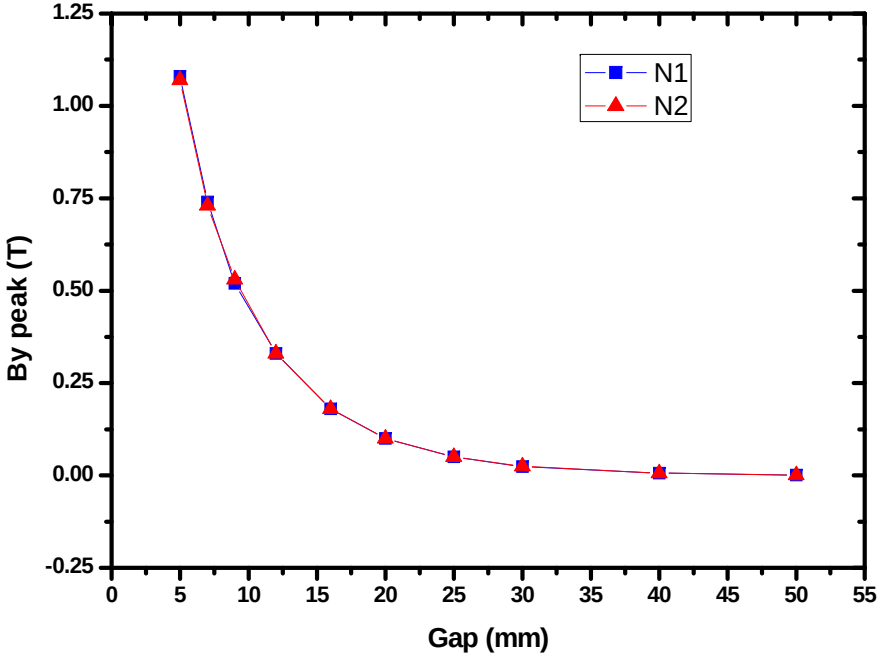
R.M.S of Phase error

Gap(mm)		5	7	9	12	20	25	30	40	50
P.E.(deg.)	N1	2.2	2.1	2.1	1.5	0.8	0.2	0.1	0.1	0.1
	N2	2.8	2.4	2.5	1.2	0.6	0.3	0.2	0.1	0.1
	Spec.	≦3								
Result		OK								

By peak field

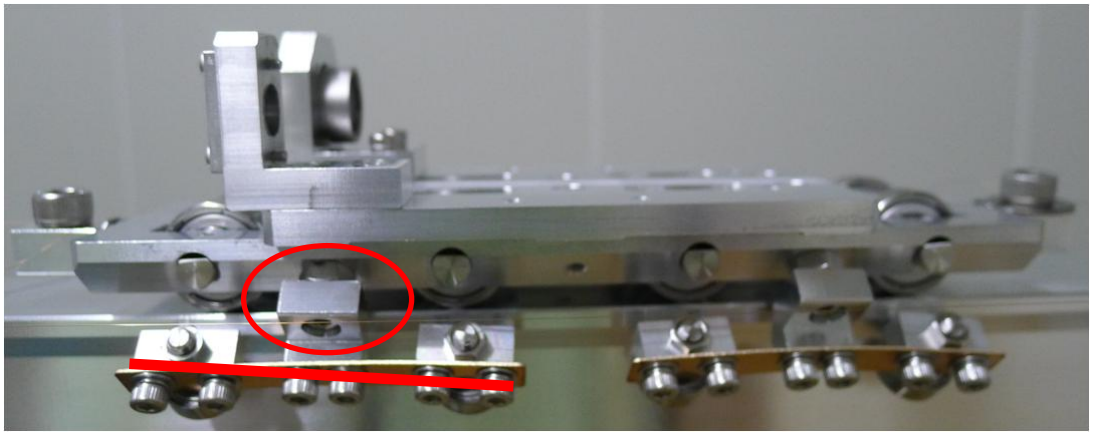
Gap(mm)		5	7	9	12	16	20	25	30	40	50
Bg(T)	N1	1.08	0.74	0.52	0.33	0.18	0.1	0.05	0.024	0.0059	0.0014
	N2	1.07	0.73	0.53	0.33	0.18	0.1	0.05	0.025	0.0059	0.0014

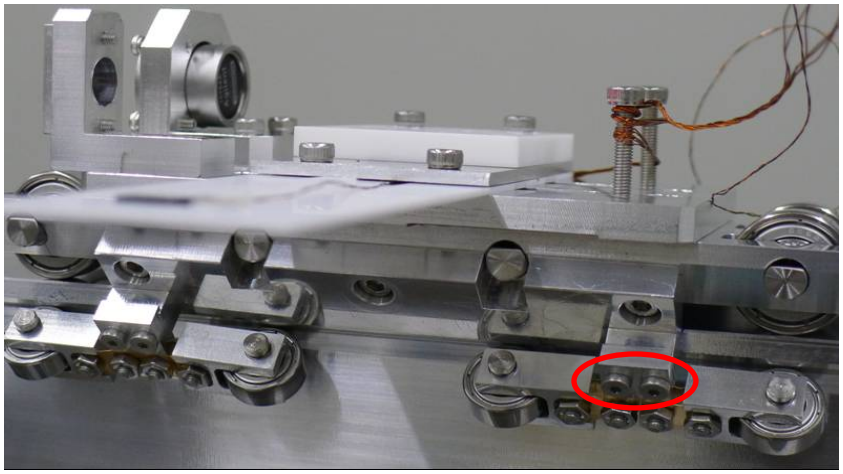




Improvement

- Step between two rails : manufacture a rail in one piece.
- Modification of the carriage : the carriage should clamp on the rail tighter.





	Phase error	dB (G)	1st integral (G.cm)	2nd integral (G.cm²)
New	0.13	1.1	9.42	673
Old	0.15	2.1	13.24	807

Summary

- Two IU22-2m are designed at NSRRC and fabricated by Hitachi Metal in Japan.
- We developed a system to measure the magnetic field performance in a vacuum chamber to check these IUs after there were delivered to Taiwan.
- Although there are small differences after the vacuum chamber assembly, the magnetic performances are still within our specifications.
- This system is modified to measure the incoming IU22-3m.
- In the future, this system will be further improved to do measurement in vacuum and

Thanks for your attention