NEW DEVELOPMENT OF CERAMICS CHAMBER WITH INTEGRATED PULSED MAGNET FOR PULSED MULTIPOLE INJECTION AT KEK-PF

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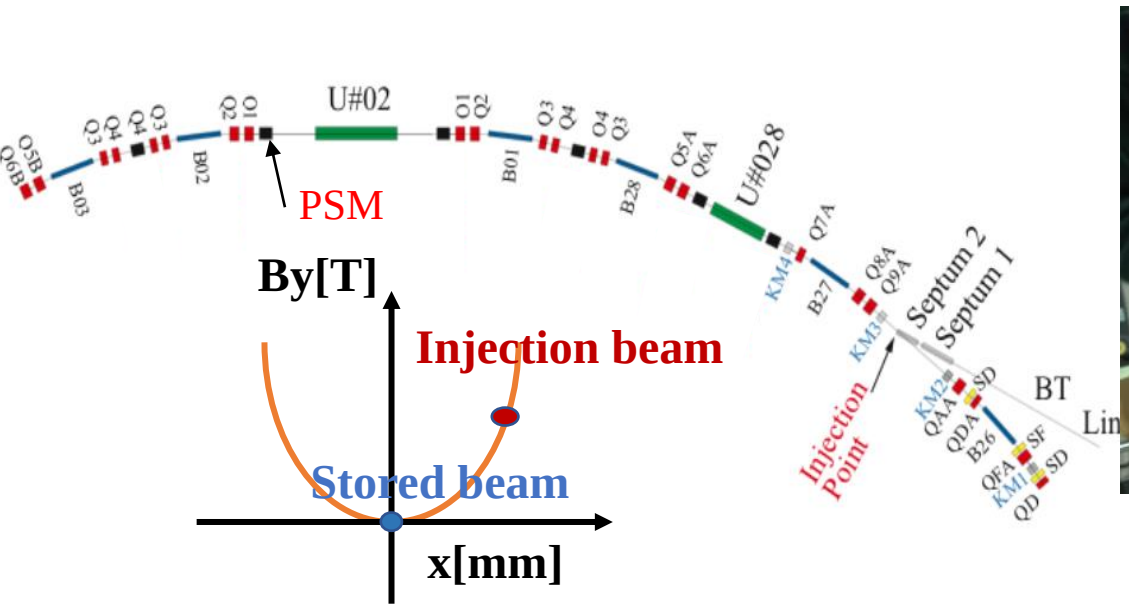
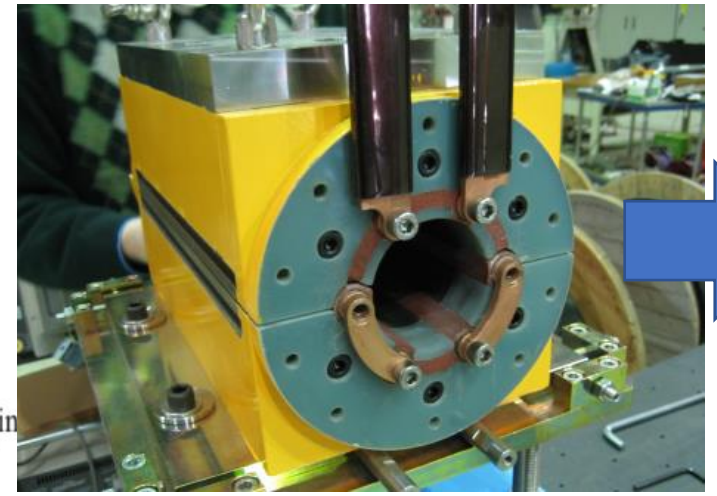
Outline

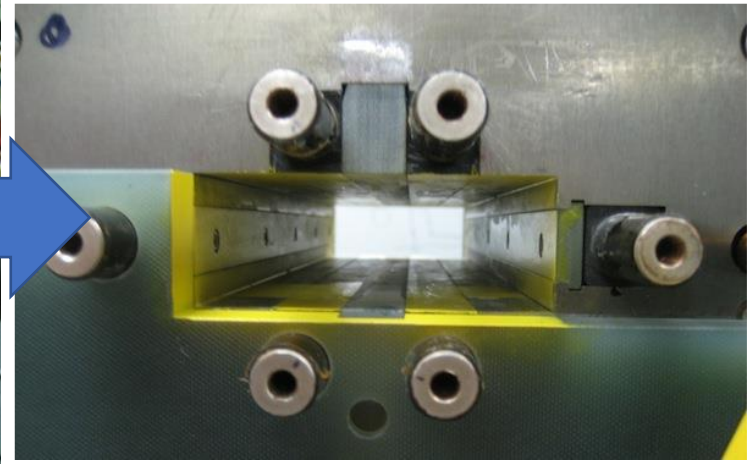
- Pulsed multipole injection at KEK-PF
- Development of Ceramics Chamber with integrated Pulsed Magnet
  - Introduction
  - Design for an octupole type pulsed magnet for multipole injection scheme
- Preliminary tests to examine basic performance
  - Durability test (heating cycle baking)
  - Current excitation test
  - Magnetic field measurement
- Summary

Pulsed multipole injection at KEK-PF

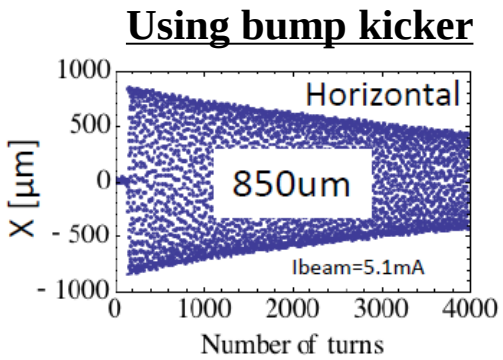


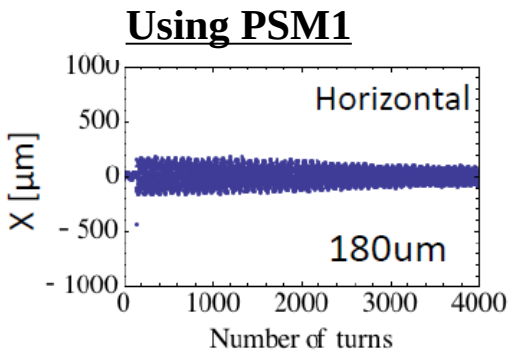


PSM1

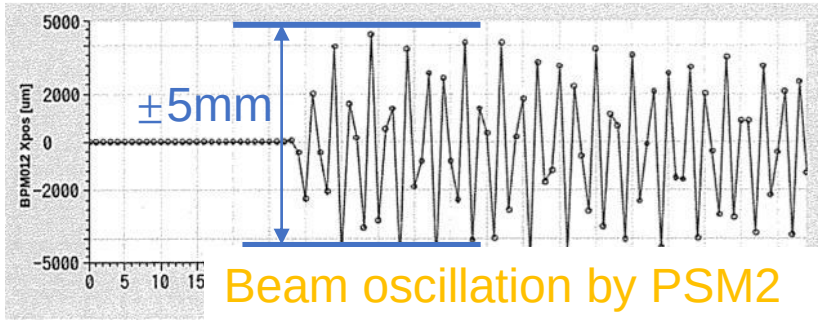


PSM2





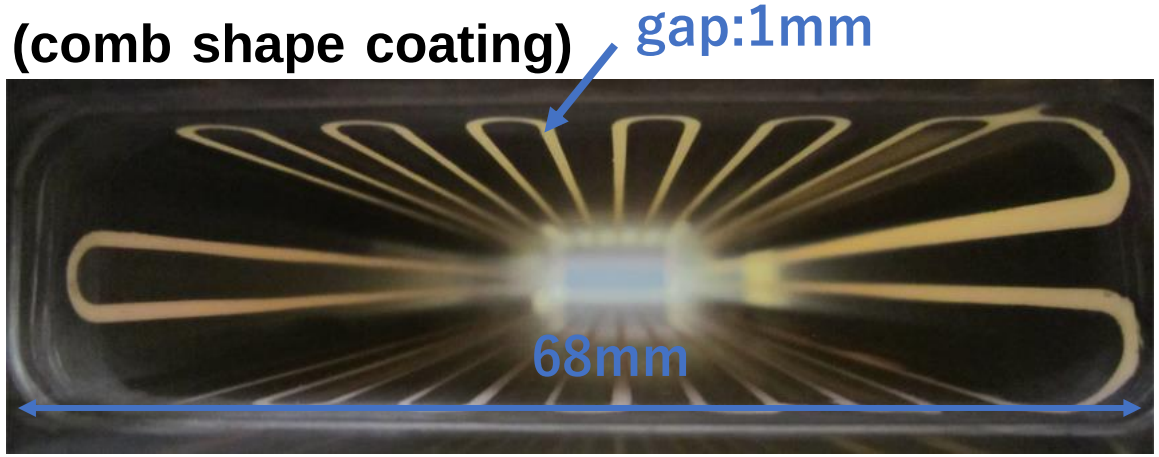
- The PSM1 injected beam successfully and it's the first experiment for a nonlinear kicker injection in the world. Beam oscillation was reduced, but still existed.
- After upgrading into PSM2 to increase injection efficiency, strong stored beam oscillation appeared.



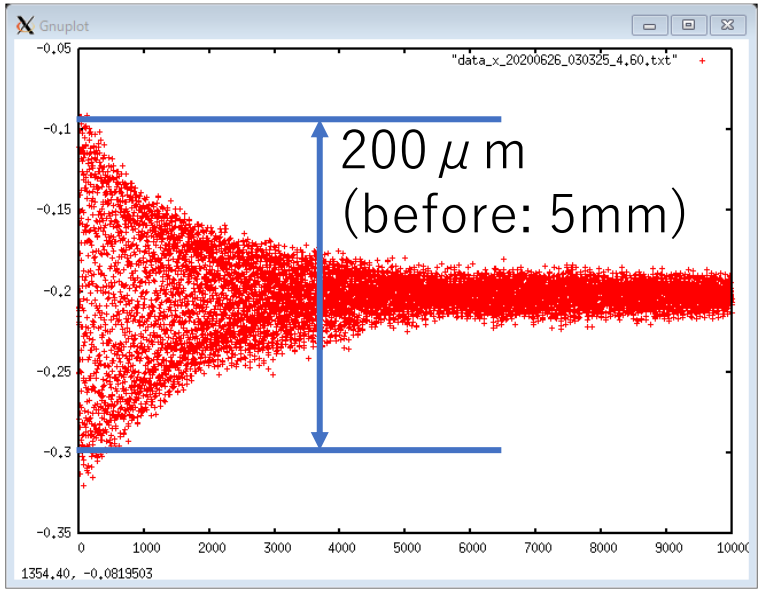
Beam oscillation by PSM2

Eddy current effects in PSM

New duct of PSM2
(comb shape coating)



Two eddy current sources that cause large oscillation
- Coating
- Iron core



- The eddy current effect of coating in PSM2 can be removed by optimizing the shape of coating.

H. Takaki *et al.*, IPAC'**2021**, WEXC06

- The magnetic field due to eddy current effect of iron-core was observed.

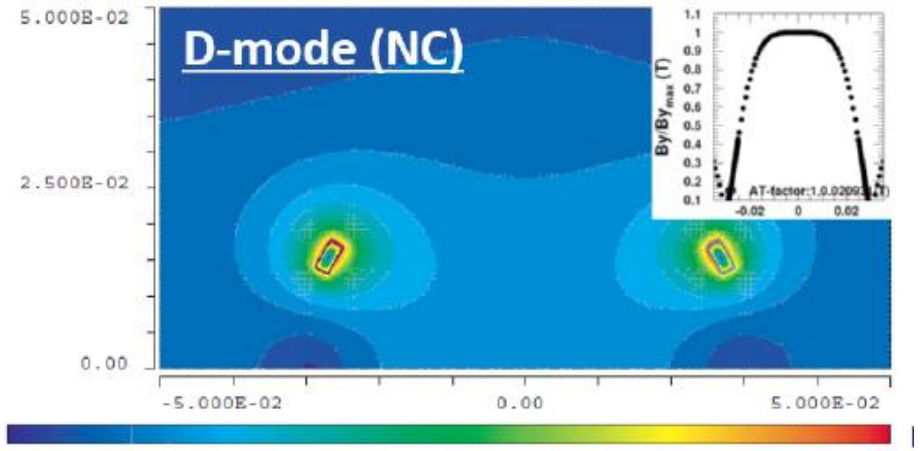
Y. Lu *et al.*, PASJ'**2020**, WEPP45

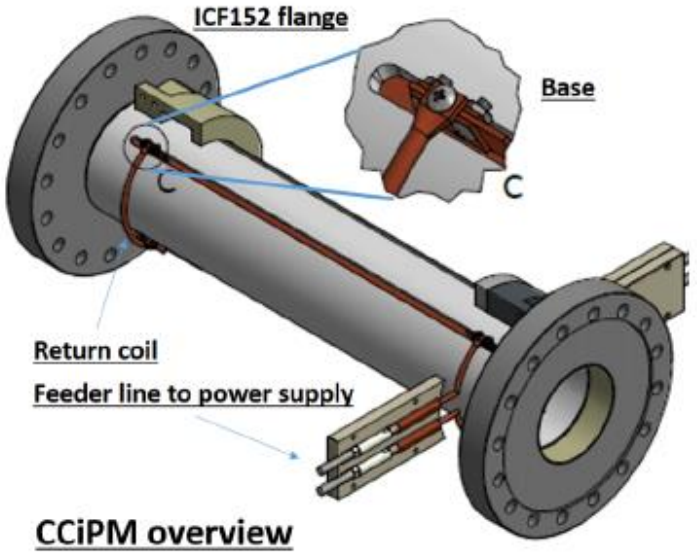
- Eddy current effect of iron core magnet still remained.

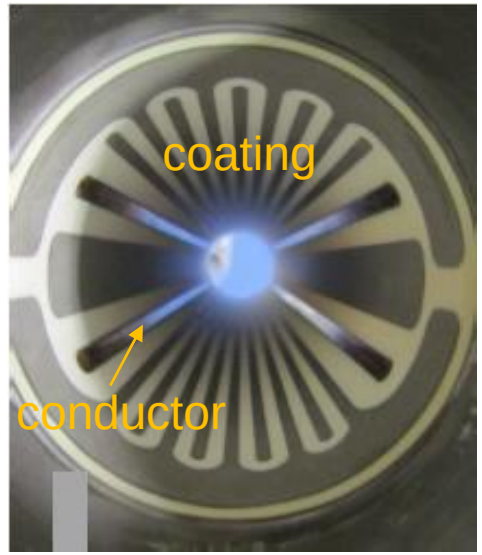
For the next generation light source, there is a higher requirement on suppression of beam oscillation.
To perform multipole injection perfectly, air-core pulsed magnet is necessary.

Ceramics Chamber with integrated Pulsed Magnet(CCiPM)

The Ceramics Chamber with integrated Pulsed Magnet(CCiPM) is developed by C. Mitsuda and KYOCERA Co from 2012 for pulsed dipole kicker at first.
Figures below shows information about the initial type CCiPM-Φ60, whose bore diameter is 60mm. And the copper conductor is implanted in the ceramics. Some features are listed below.





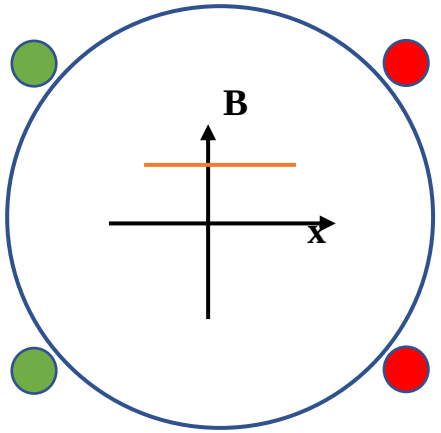


- Air core pulsed magnet
- Apply comb coating to reduce eddy current effect
- Low impedance
- Compact and Light with structural strength
- Flexible to generate multipole magnetic field

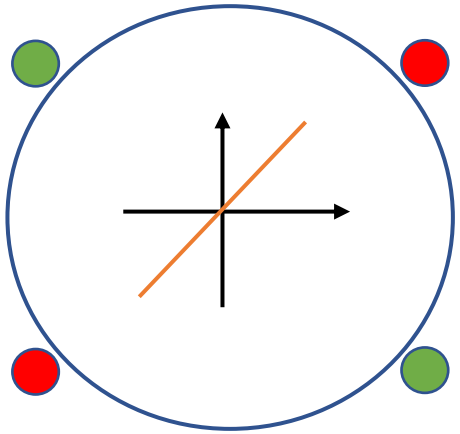
Flexibility of magnetic field

Concept: Same with design theory of air-core magnet, which is mainly applied for superconducting magnet.

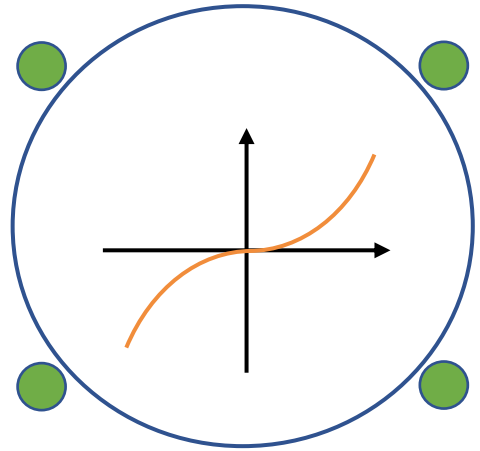
Dipole:



Quadrupole:



Octupole:



: positive current flow direction

: negative current flow direction

If there are four parallel current flows, an Octupole-like field could be generated.

Angle is an important parameter in design.

But generating sextupole magnetic field is impossible in case.

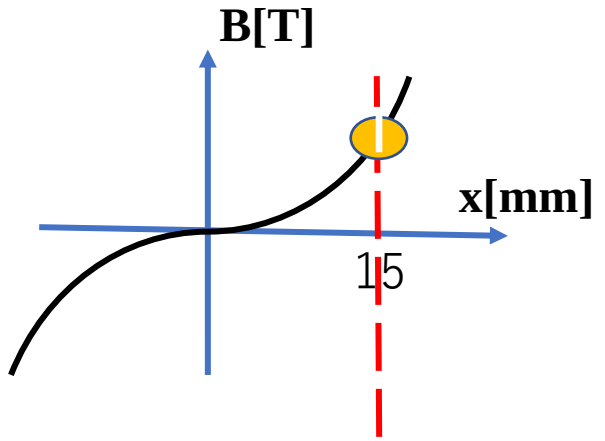
Production of CCiPM-Φ40 for PF ring

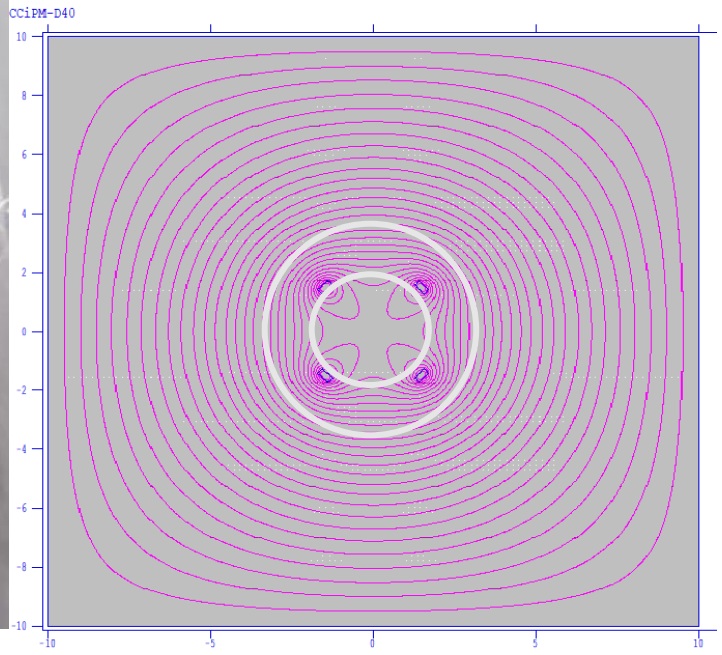
To examine the beam injection by CCiPM, a CCiPM-Φ40 of octupole type is designed for PF ring, which is fit to duct of PF.

Diameter: 40mm
Thickness of ceramics: 10 mm
Total length: 400 mm
Length of conductor: 290 mm

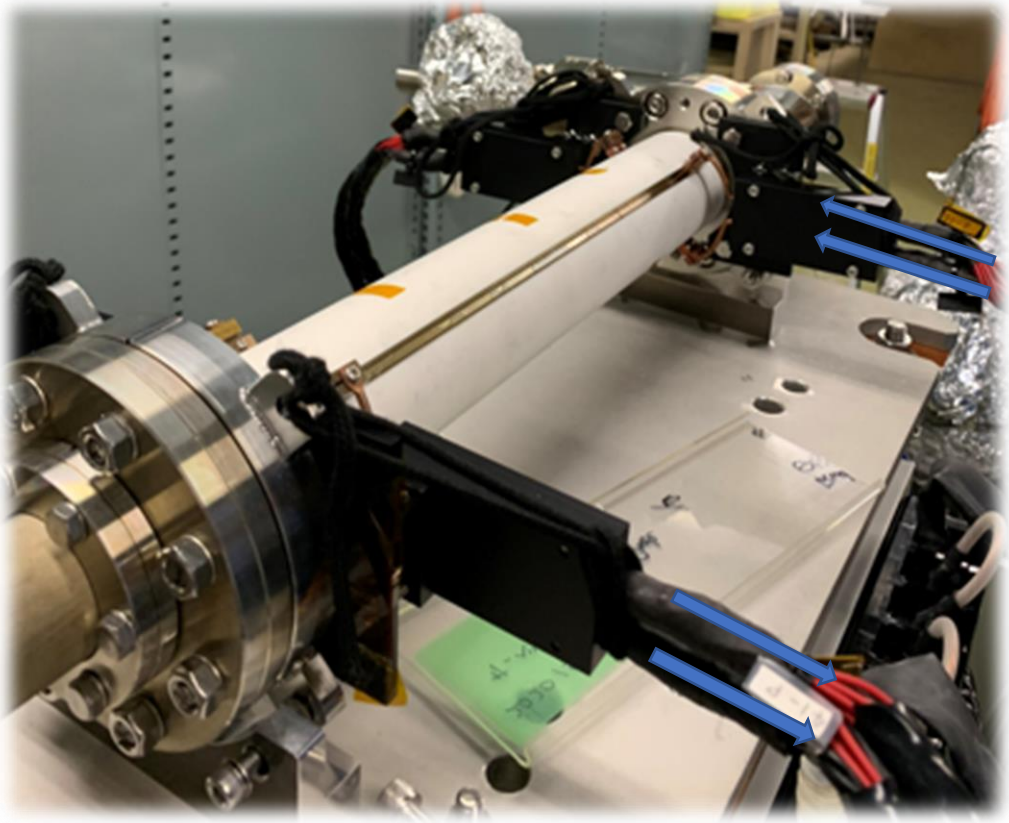
Target: Generate a flat region around center and performance of magnetic field strength is same with the PSM to replace the PSM in the ring.

(integrated field at x=15mm is 0.12 [mT·m] when current is around 3000 A)





High inductance problem



At first, the terminal block was used to make a parallel current flow, unfortunately, it's found that the inductance is 11μH by LCR meter.

In one-turn kick condition(pulse width=1.2μs) :

$$Z = \mathrm{j}\omega L \approx \mathrm{j}29\ \ \Omega$$

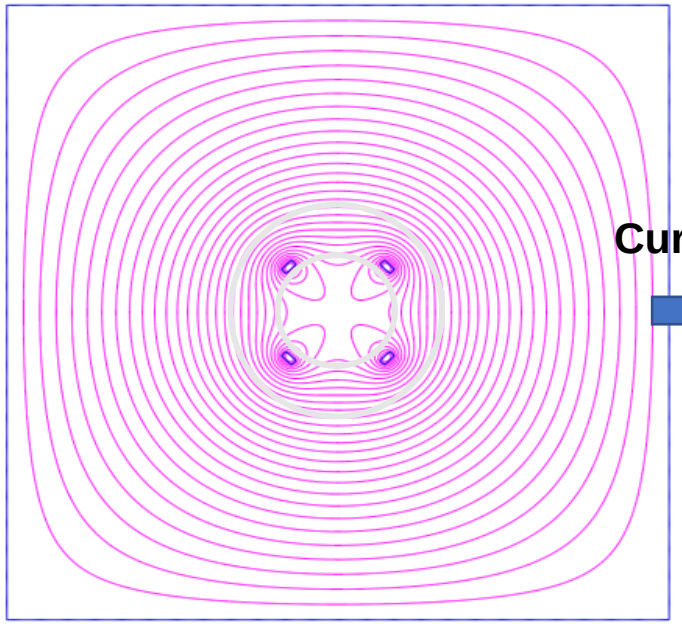
And if I=3000A, the peak pulsed voltage can reach 90kV……

Reasons are as follows

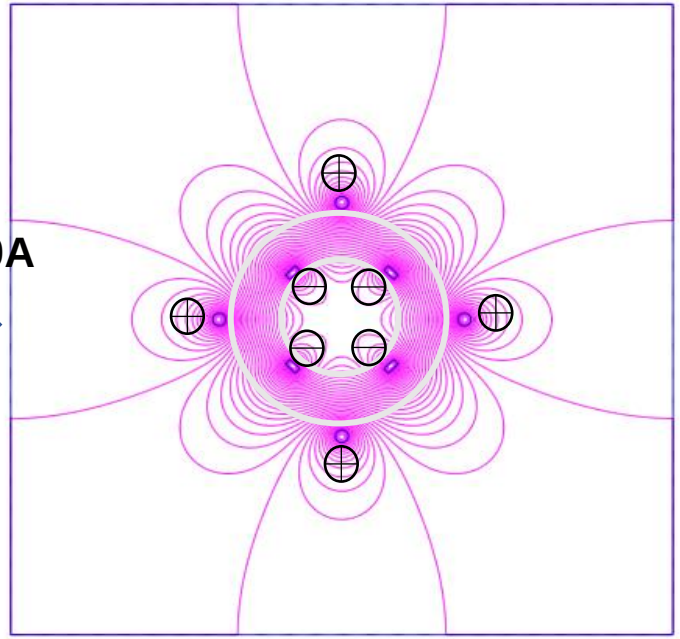
- Magnetic flux is full of space so that stored energy is large.
- Twisted cable is used to reduce the impedance of cable in dipole type CCiPM. But it doesn't work in octupole type because of parallel current. Therefore, impedance of cable can't be ignored.

How to reduce the inductance

method: Add four additional conductors on the surface of chamber to restrict magnetic flux and simplify structure.

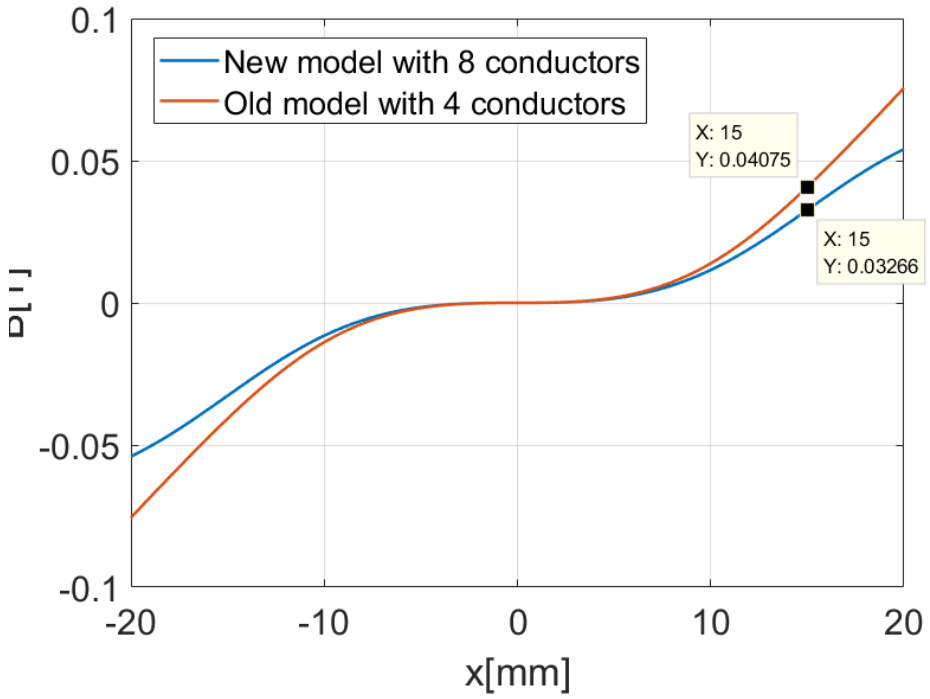


Current=3000A



0.25114 J/cm, 1.81μH

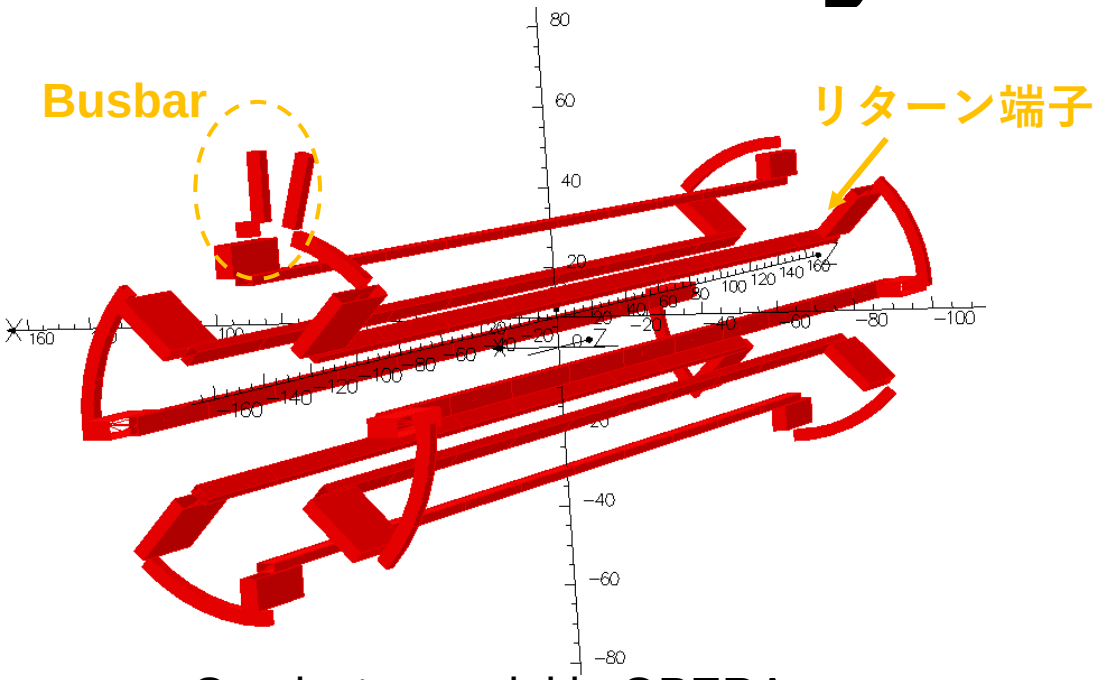
0.17883 J/cm, 1.29μH



Horizontal distribution in Poisson

- Stored energy is reduced
- Magnetic field around kick region is also increased

3D model simulation of magnetic field



Conductor model in OPERA
(length for each conductor:290mm)

- 3D magnetic field is simulated by OPERA
- Busbar structure is optimized to reduce deformation along longitudinal center axis.
- The integrated field at x=15mm is 11.1 mT·m, which is less than target value but acceptable.

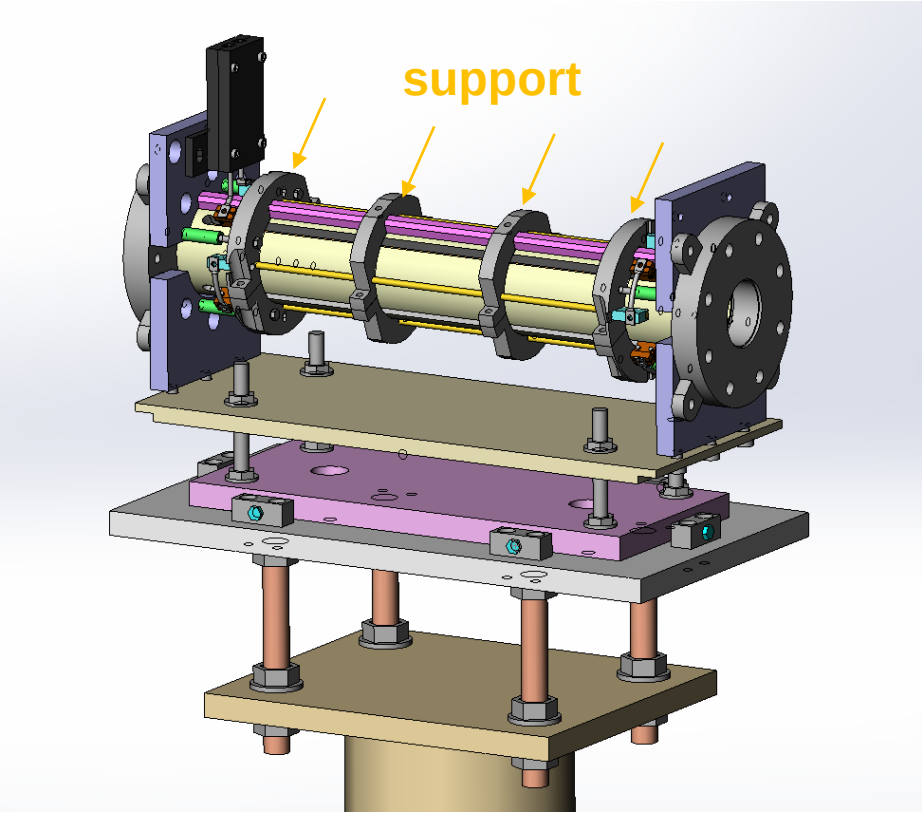
Integrated field when I = 3000A

Center	By Integrated field	Bx Integrated field
0 mm	-8.7 μT·m	1.2 μT·m

X injection	By Integrated field
15 mm	11.11 mT·m

Target value: 12 mT·m

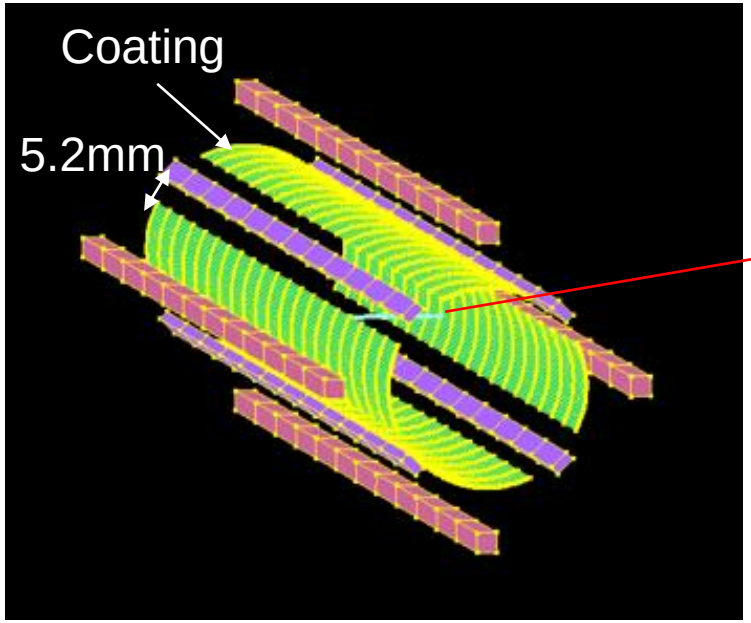
Mechanical design of new model with additional conductors

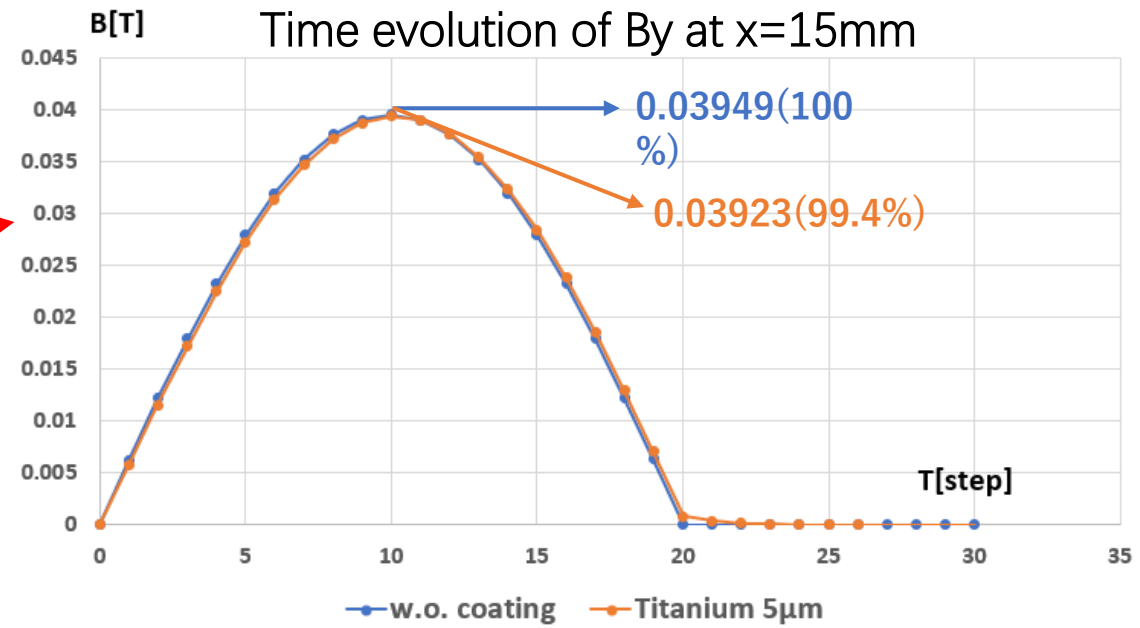


- To fix the additional conductor, a support was applied.
- Jig holds the conductors precisely to keep them in correct position by keyway.
- The material of support is non-magnetic to avoid undesirable magnetic field when pulsed current is applied.

Inner coating related to eddy current effect

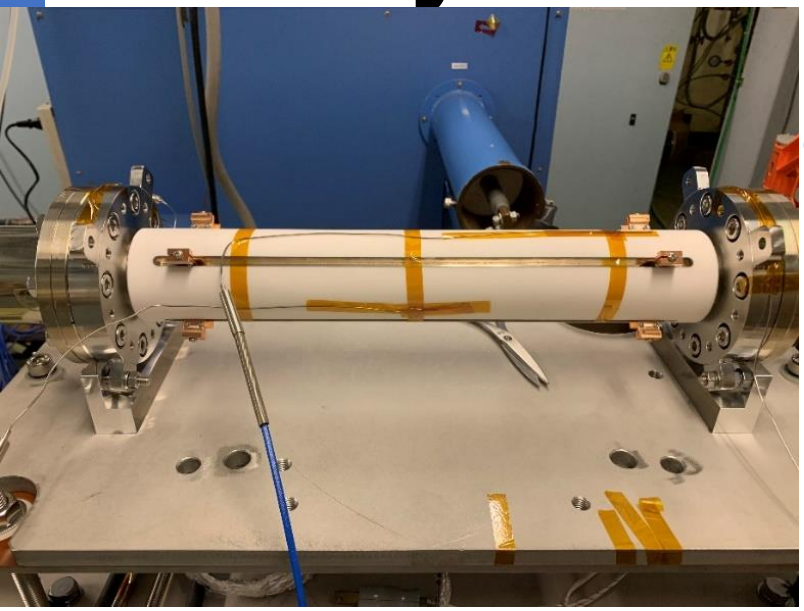
According to experimental results before, eddy current effect of coating is weak if chamber is circular shape. A model in ELF was made to examine it by transient magnetic field simulation. And it showed that eddy current effect of coating is negligible.

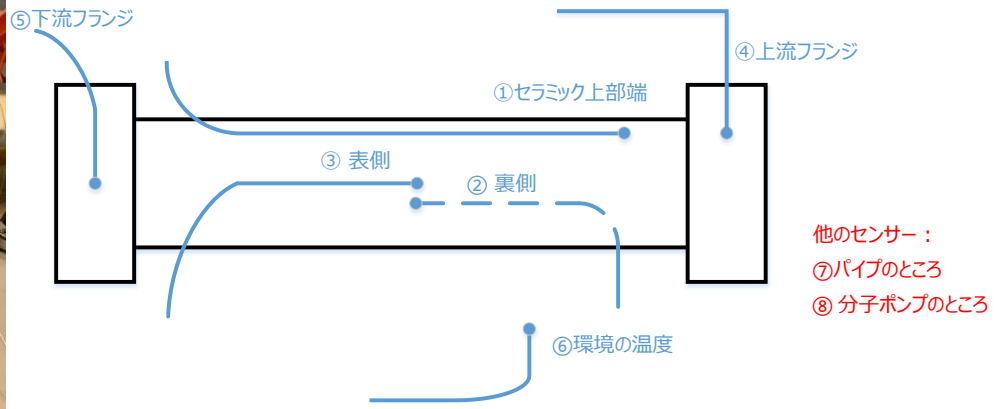


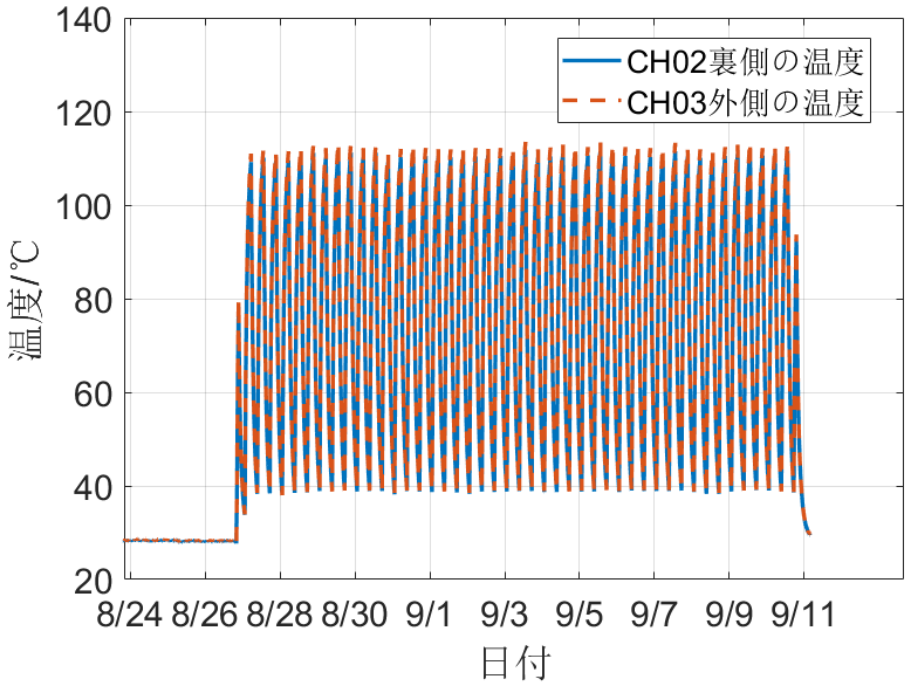


- Uniform Titanium coating with 5 μm.
- Pulse width of applied half-sine current is 1.2 μs, which corresponds to 20 steps in simulation
- Gap between coating and conductor is 5.2mm to avoid electric discharge.
- Low conductivity of titanium and circular shape.

Durability test for thermal stress and vacuum force

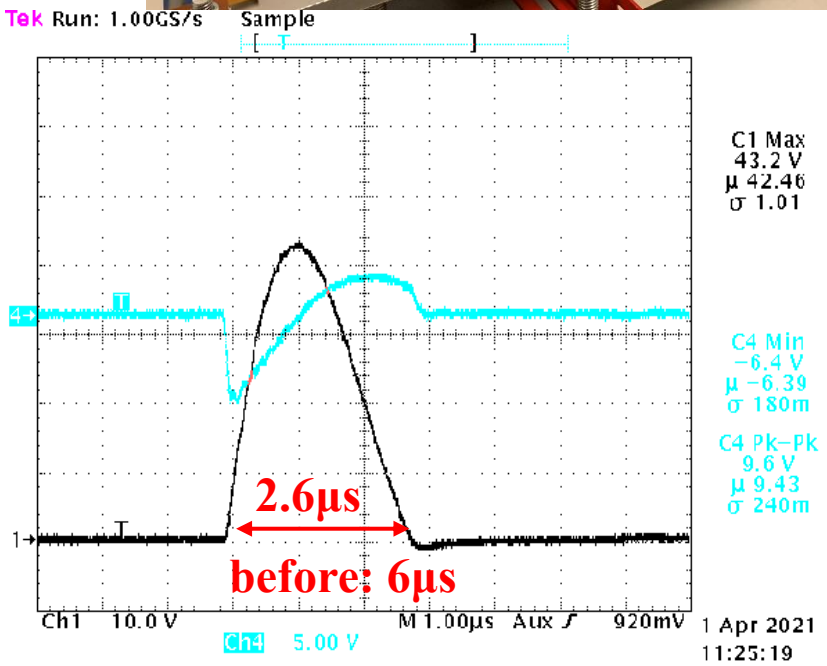


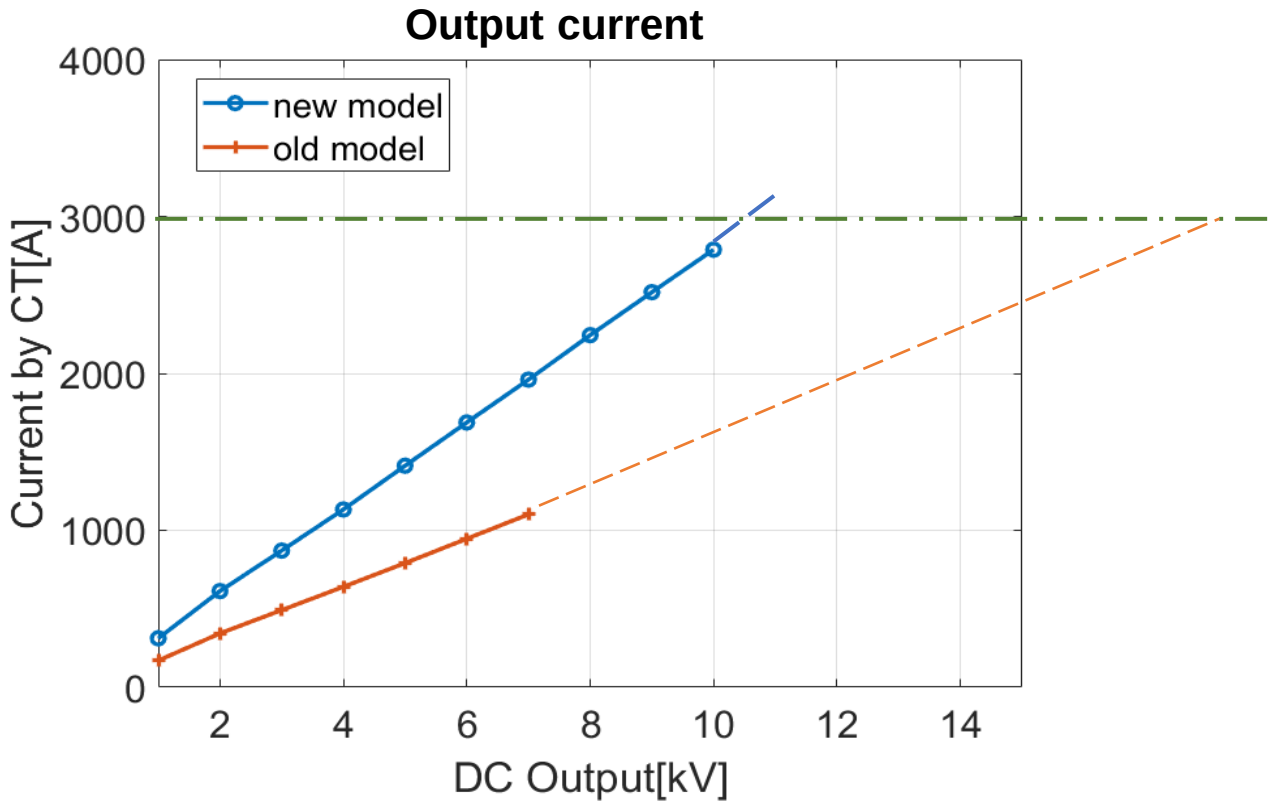




- Heating cycle baking was performed to simulate a severe condition which may happen in storage ring.
- One heating cycle starts at room temperature, ramps to around 120 ℃ and holds for 4 h, then cools down naturally for the other 4 h.
- Baking continued for 38 days totally.
- Finally vacuum condition reached 7.6×10^{-8} Pa.

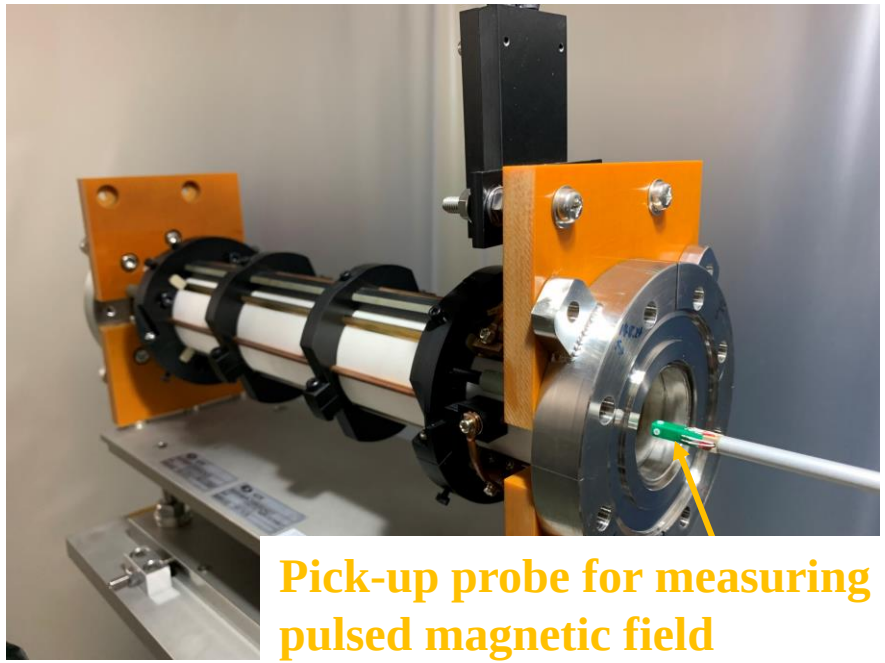
Current excitation test



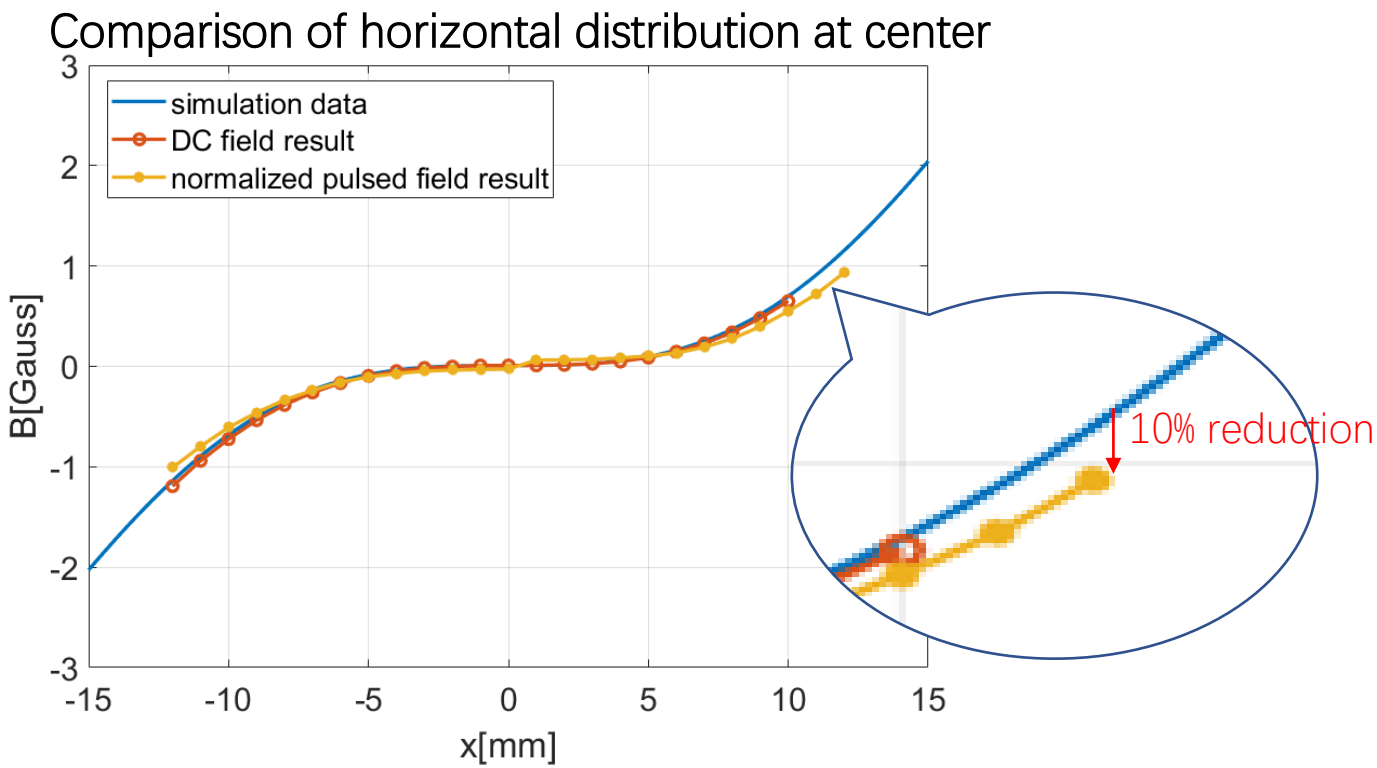


- Inductance was measured by LCR meter and it's about **1.45 μH**
- The maximum current is close to 3000 A but there is a limitation of power source output. And it shows good linearity.

Magnetic field measurement



Pick-up probe for measuring pulsed magnetic field



- Both DC and pulsed magnetic field were measured. DC magnetic field is measured by a hall probe and pulsed magnetic field is measured by a small pick-up probe.
- From the comparison of horizontal distributions, DC magnetic field can match the simulation data, but normalized pulsed magnetic field value is smaller
- The test bench made by stainless steel and copper conductor are two eddy current sources. But in simulation, eddy current effects of them are negligible.

Summary

Because iron-core pulsed magnet has eddy current effects, air-core pulsed magnet should be developed to do multipole injection.

- Design an Octupole pulsed magnet based on CCiPM
  - Small impedance by adding four conductors
  - Mechanical design
  - Uniform coating
- Some experiments has been conducted to evaluate the performance
  - Baking and vacuum extraction
  - Current excitation test
  - Magnetic field measurement

The pulsed magnetic field result is against expectation, and this issue will be investigated soon.

THANKS FOR YOUR ATTENTION

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