Analysis of Interdependent Multipole Field Pattern and Complement Dipole Field Quality

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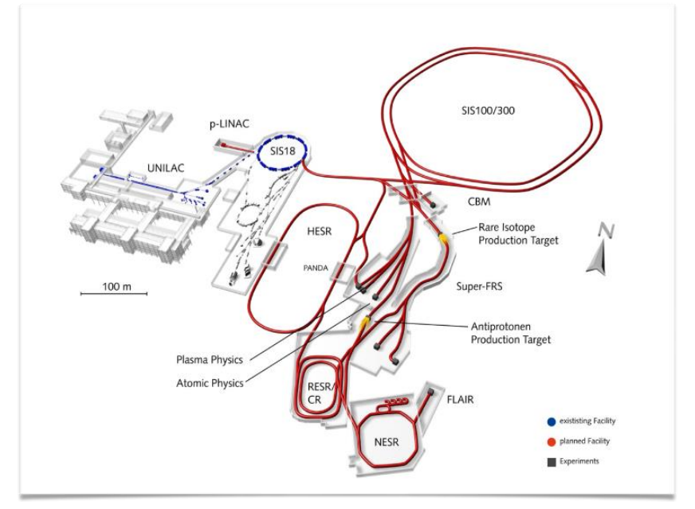

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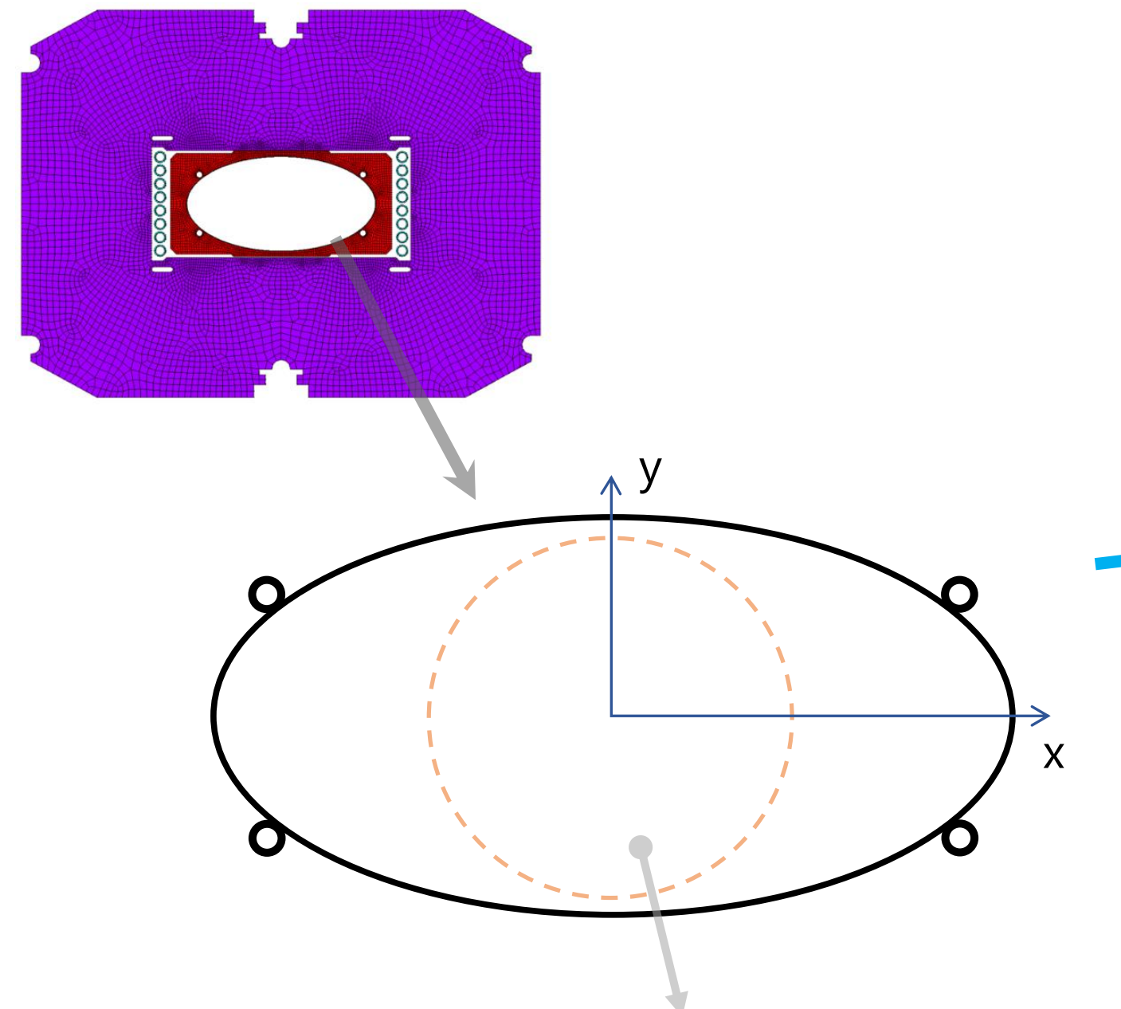
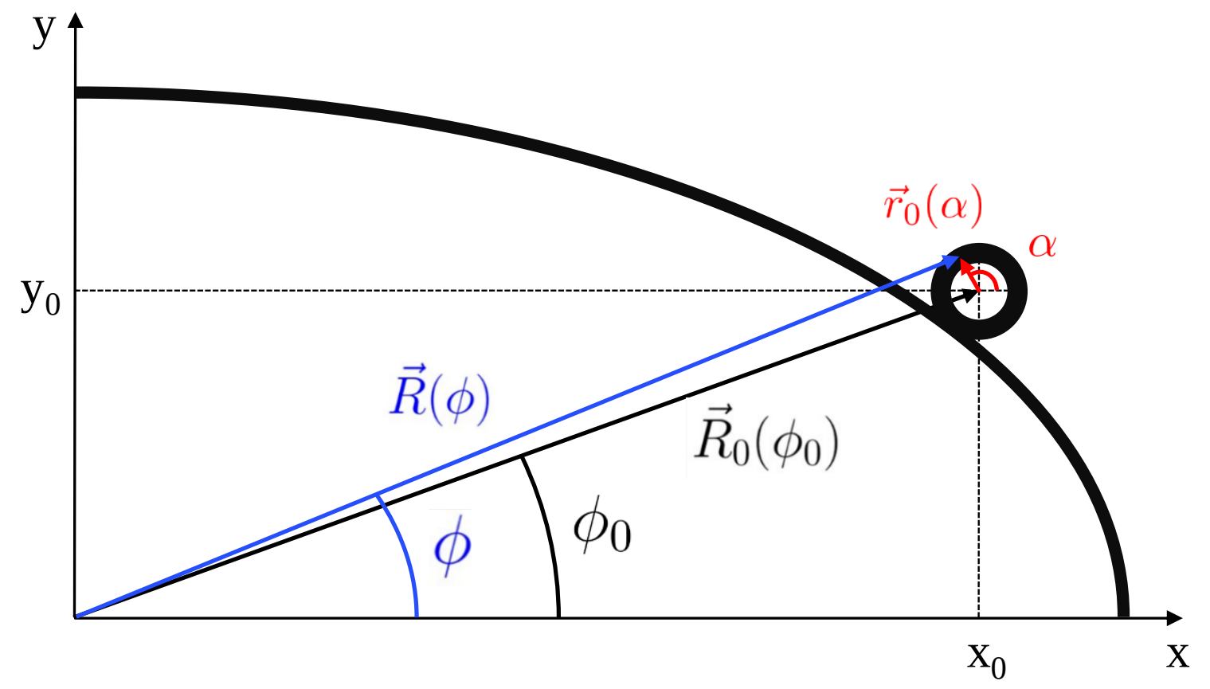
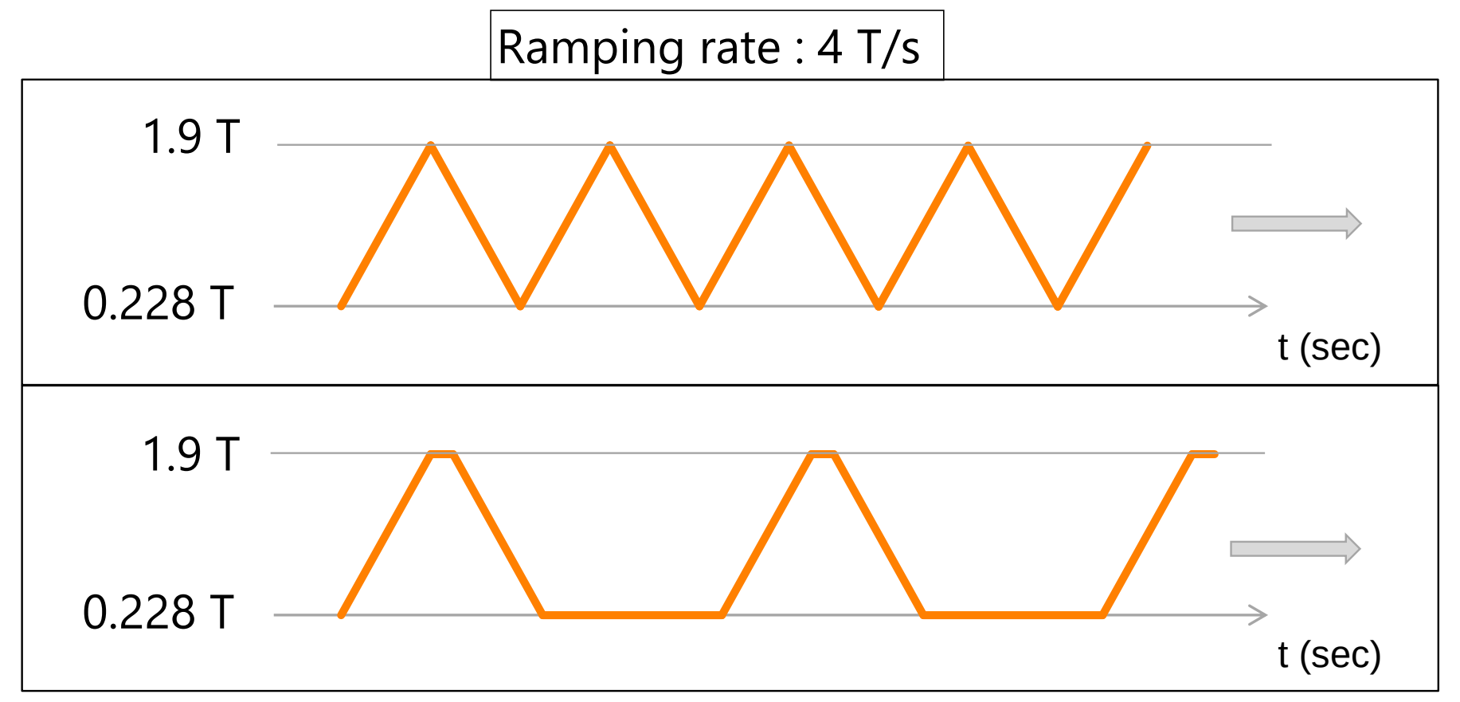
- We present a mutual influence of the magnetic field and the corresponding analytical method. The two different geometric components have different eddy current profiles. And the corresponding magnetic fields disturb the operation field quality. The beam tube with the cooling pipe are the closest objects to the accelerated beam with exposing the same magnetic field. Therefore, the stray field from these components needs to be considered in magnet field quality.
- The cooling pipe in an optimal position shows the opposite polarity with the same magnitude of one multipole field component corresponding to that of the beam tube.
- The present geometric field analysis identifies the pattern of the multipole field and the cooling pipe position. The eddy current in the optimal conductor geometry is able to complement the operation field quality.

SIS100 Dipole Magnet and Field Operation

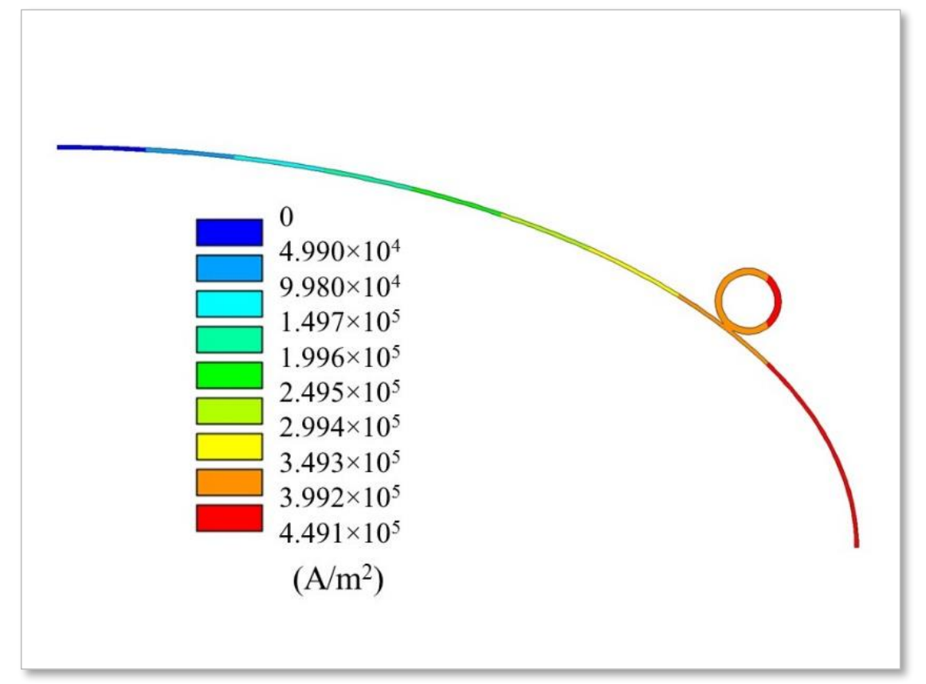




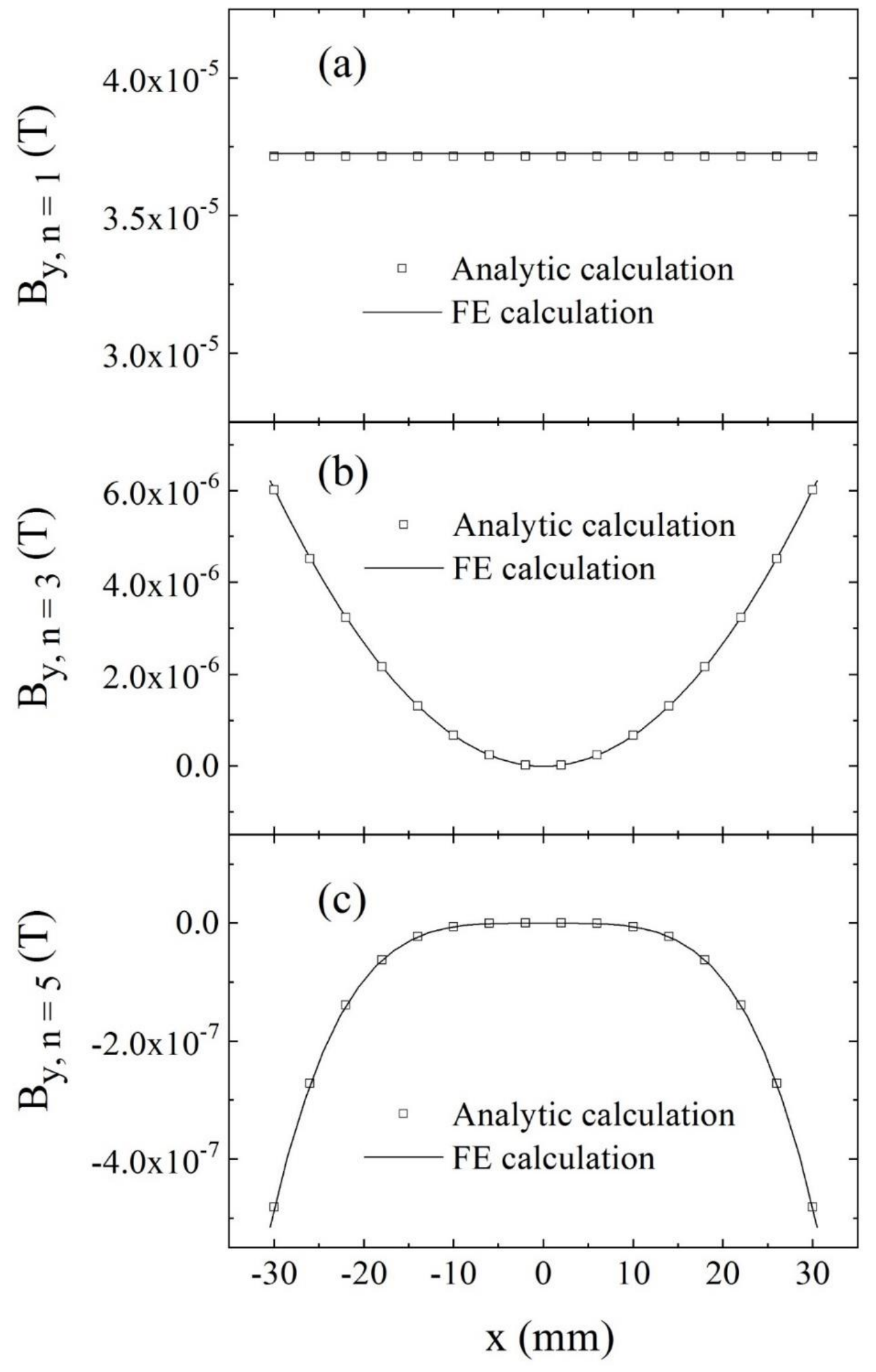
- Main Beam Dynamics Region, -30 mm ≤ r ≤ 30 mm.
- This region needs a high-quality dipole field.



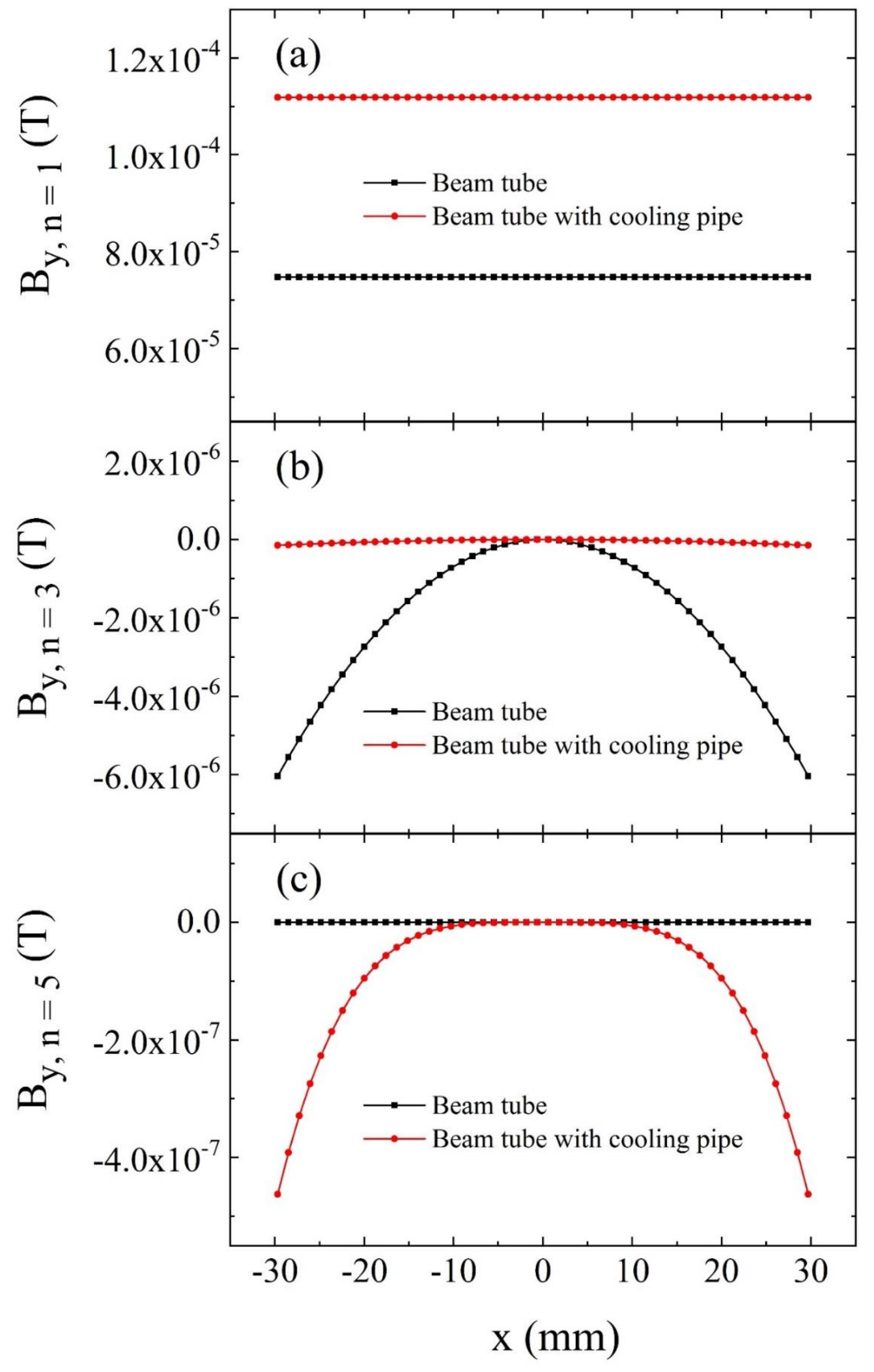
The magnitude of the eddy current density
- Increase linearly on the horizontal x-axis.



$B_{y,n\,=\,1,\,3,\,5}$ Profiles and the Variable Transformation



The cooling pipe multipole fields.



Multipole fields of the beam tube with and without the cooling pipe.

$B_{y,n}(x)$

Change variable : $\phi \to \alpha$

$$B_{\theta,n}(r,\theta) = -\frac{2\mu_0}{\pi} r^{n-1}\cos(n\theta)\int_{I(0)}^{I(\frac{\pi}{2})}\left(\frac{1}{R(\phi)}\right)^n \cos(n\phi)\,dI(\phi) \Rightarrow B_{\theta,n}(r,\theta) = -\frac{2\mu_0\dot{B}}{\pi\rho} r_0 h_{cp} r^{n-1}\cos n\theta \int_0^{2\pi}(r_0\cos\alpha + x_0)\left(\frac{1}{R(\alpha)}\right)^n f(n,\alpha)\,d\alpha$$

$B_{r,n}(r,\theta)$ with the same method

$$R(\phi) = \left(R_0^2 + r_0^2 + 2r_0R_0\cos(\alpha - \phi_0)\right)^{\frac{1}{2}} = R(\alpha)$$

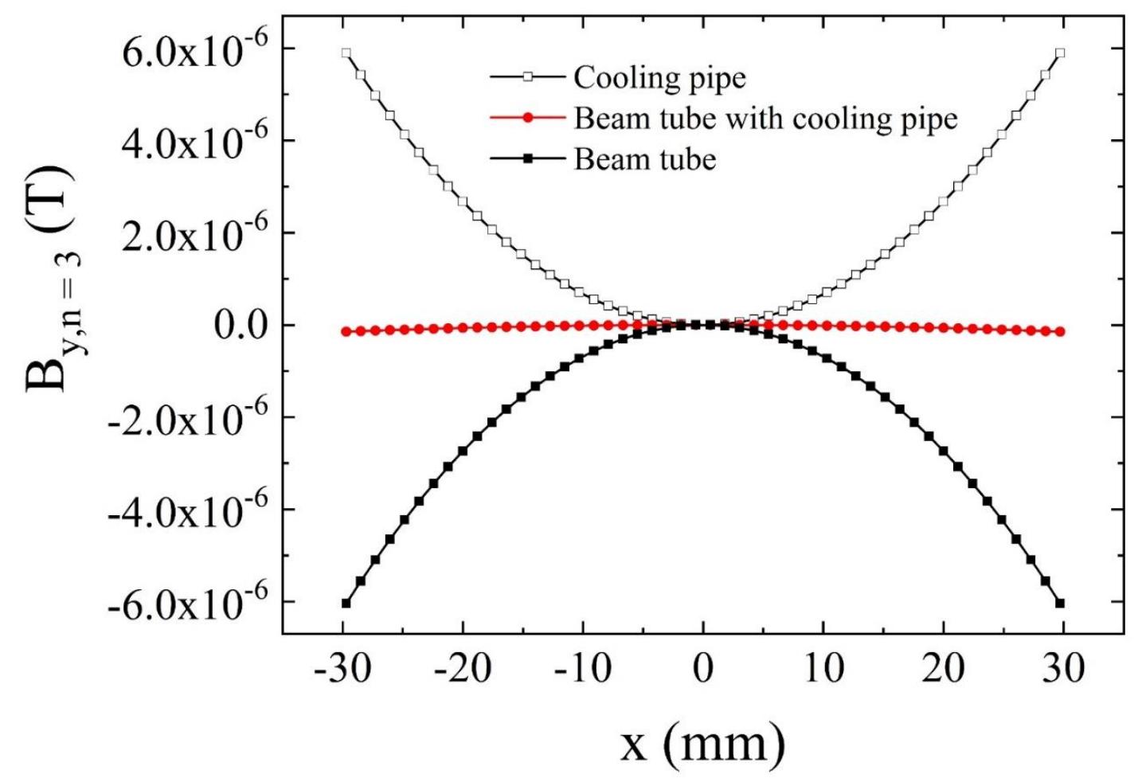
$R_0 = 55.217$ mm, $\phi_0 = 0.3426$ rad

$$dI(\phi) = j(\phi)dA_{cp} = \frac{\dot{B}}{\rho}(r_0\cos\alpha + x_0)r_0h_{cp}d\alpha = dI(\alpha)$$

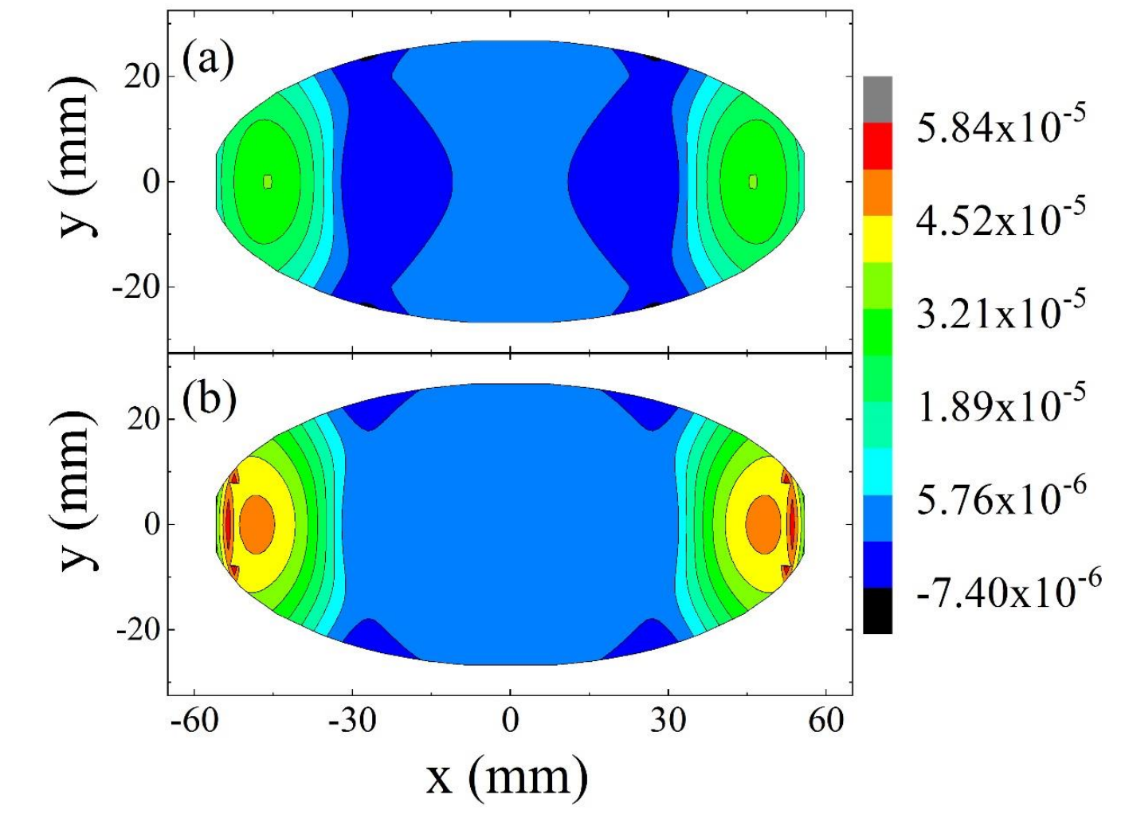
$$j(\phi) = \frac{\dot{B}}{\rho}R(\phi)\cos\phi = \frac{\dot{B}}{\rho}(r_0\cos\alpha + x_0) = j(\alpha)$$

$$\begin{aligned}\cos n\phi &= \frac{1}{2}\left\{(2\cos\phi)^n + \Sigma_{k=1,2,3\ldots}^{k_{max}}\left[\frac{(-1)^k n}{k}\binom{n-(k+1)}{k-1}(2\cos\phi)^{n-2k}\right]\right\} \\ &= \frac{1}{2}\left\{\left(\frac{2(r_0\cos\alpha + x_0)}{R(\alpha)}\right)^n + \Sigma_{k=1,2,3,\ldots}^{k_{max}}\left[\frac{(-1)^k n}{k}\binom{n-(k+1)}{k-1}\left(\frac{2(r_0\cos\alpha + x_0)}{R(\alpha)}\right)^{n-2k}\right]\right\} \equiv f(n,\alpha)\end{aligned}$$

n = 3 multipole component

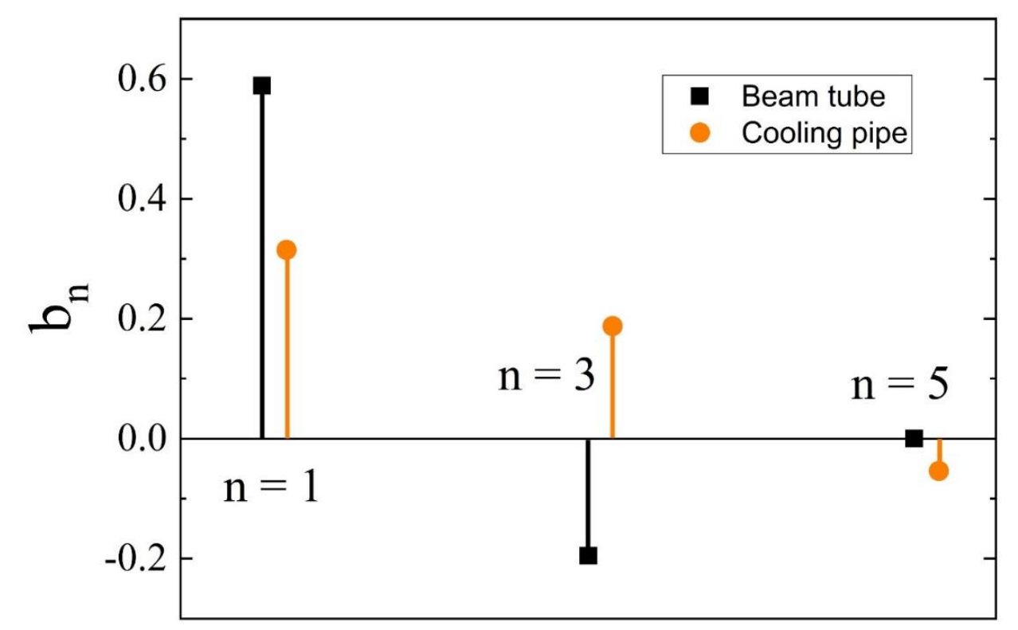


The n = 3 field from two components have interdependence and erased.



The $B_{y,n=3}$ profile. (a) The beam tube without the cooling pipe. (b) The beam tube with the cooling pipe. The field profile is more uniform compared to (a) in -30 mm ≤ r ≤ 30 mm.

The Comparison of the multipole coefficients b_n



- The n = 1 of the two components has the same polarity. And the applied field is dipole magnetic field. Therefore, the same polarity is not the field quality disturbance but the magnitude variation. The magnet operation parameters can adjust the magnitude.
- The main stray field n = 3 of the two components have opposite polity. In this condition, the two eddy current conductors reduce the stray field each other.
- The n = 5 field is 0.287 times smaller than n = 3 field. Therefore, the effect of the n = 3 is bigger than that of the n = 5.

Conclusion

- In general, eddy current has a negative effect on the designed field quality. However, this result indicates a positive effect, which improves the operation field quality. When the two different geometric structures have the interdependent field pattern, the operation field can maintain own field quality.
- This paper presented the magnetic field compensation of the eddy current in the two different geometric conductors.
- The comparative field analysis found the cooling pipe position of $R_0(\phi_0)$ where produces the opposite polarity with the same magnitude of the n = 3 field compared to that of the beam tube.
- Consequently, the eddy current in the cooling pipe decreases the stray field of the beam tube and complements the total field quality. We found the positive effect of the eddy current.