Particle Beam Lasers

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

# Optimization Strategy and Code for the Optimum Integral Design

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May 29, 2025

# Optimum Integral Magnet Design Approach

## Optimize cross-section and ends together to obtain an integrated cosine theta distribution:

$I(\theta) \cdot L(\theta) = I_o \cdot L_i(\theta) \propto I_o \cdot L_o \cdot \cos(n\theta)$

For no wedges or end spacer, function is linear ==> Modulate it to cos theta

- Full-length midplane turn defines the length of the magnet

Essentially no loss due to magnet ends

Turns at midplane contribute much more to field than turns at any other angle. In the "Optimum Integral Design" midplane turns extend full-length

# Computation and optimization of field harmonics

## Expression for harmonic $b_n$ :

for a line current located at $(a, \phi)$

$$b_n = 10^4 \left(\frac{R_0}{a}\right)^n \cos\left[(n+1)\,\phi\right]$$

reference radius $R_0$

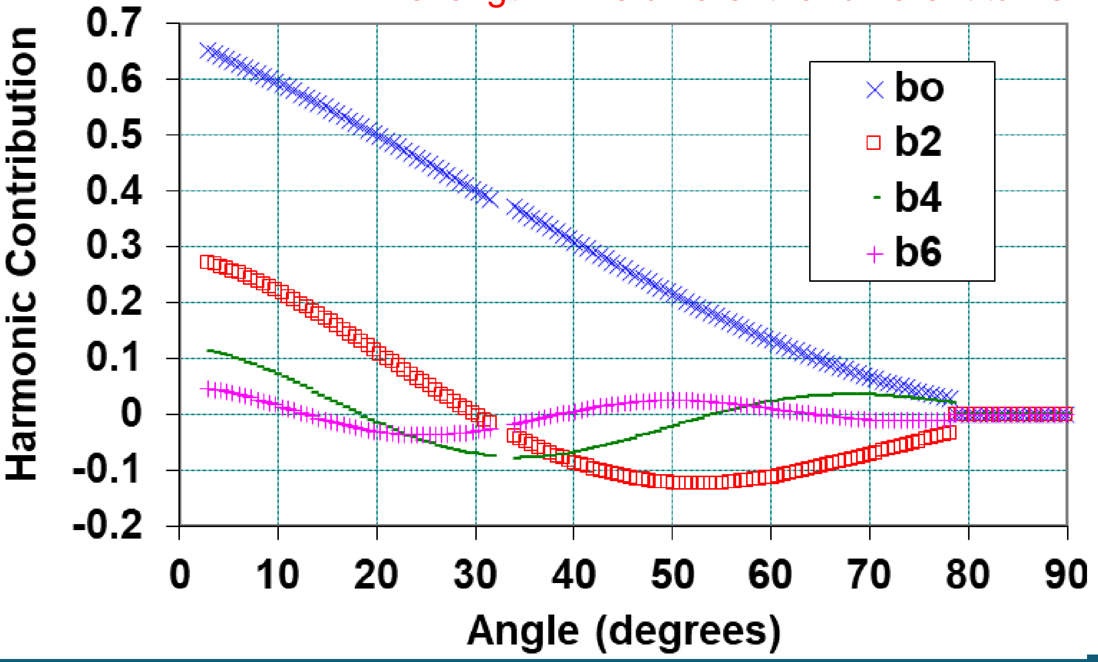
Above formula is valid either in 2-d for an infinitively long line current and in 3-d if we cover the entire space (for practical reasons where the field is non-negligible).

If the length of turns is different, the integral harmonics ($B_n$) can still be computed by the above formula, if it is multiplied by the length of each turn.

## Integral field harmonics ($B_n$):

$$B_n = 10^4 \left(\frac{R_0}{a}\right)^n . L . \cos\left[(n+1)\,\phi\right]$$

The length “L” is different for different turns




(Note: $b_2$ is sextupole)

**Turns at midplane contribute much more to field than turns at any other angle. In the “Optimum Integral Design” midplane turns extend full-length**

# Chi square ( $\chi^2$ ) function

Chi square ($\chi^2$ ) function, which is used to minimize a set of "*i*" parameters together, is defined as:

$$\chi^2 = \sum_i w_i \cdot (C_i^2 - D_i^2) \ ,$$

where $C_i$ is the computed value of the $i^{th}$ parameter, $D_i$ is the design value of the $i^{th}$ parameter and $w_i$ the weight for the $i^{th}$ parameter.

# How Optimum Integral Design code differs from most other 3-d codes in computing and optimizing integral harmonics

- Most codes first compute field (or vector potential) along the length at several places and then compute and integrate field harmonics and then optimize them.
- Optimum integral code directly computes integral harmonics of interest by integrating the value from each conductor. Iron is included as the image current.

➢ This is an order of magnitude faster. The formulae are valid when the field is 2-d or when it is integrated over the entire length. Cylindrical part of the conductor (going from the lead end to return end) does not contribute to field harmonics. A section of the conductor which connects straight-section to cylindrical part (small in most direct wind magnets), is approximated with a set of line currents.

➢ **Chi square ( $\chi^2$ ) function is minimized for a set of n-harmonics with chosen weightage to each of those n harmonics.**

➢ The downside is that it doesn’t do anything else – like peak field, field in the aperture, etc., etc., etc.. To overcome that limitation, we create output files which are input for OPERA (or RAT) and those calculations are performed there.