Effect of Construction Errors in the Helical Undulator for the RHIC Electron Cooler

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RHIC

Introduction

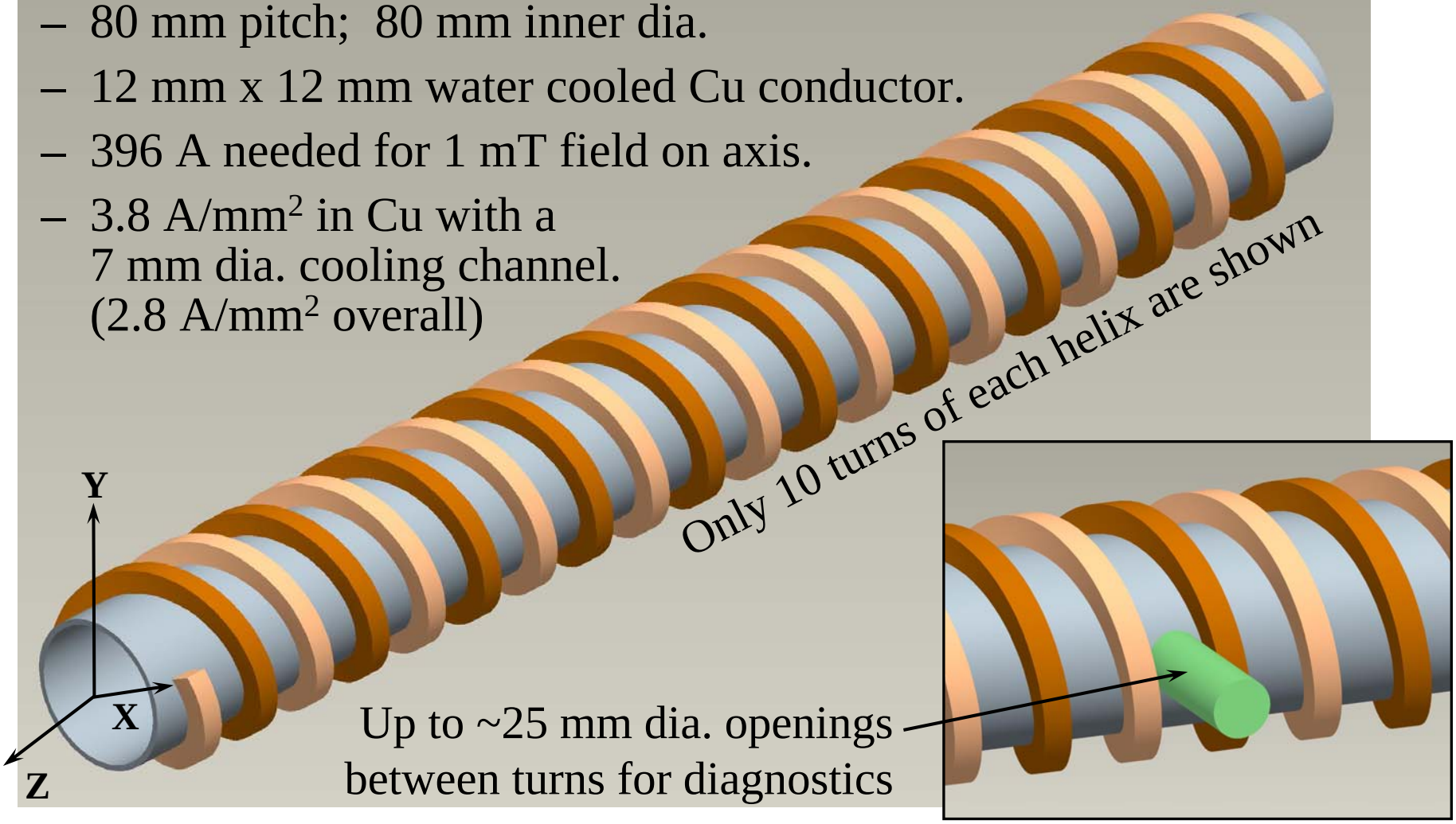
- The present plan for the RHIC electron cooler calls for a low field helical undulator (non-magnetized cooling).
- The undulator is used to suppress recombination, resulting in potentially increased average luminosity, despite a reduction in friction force.
- This talk briefly describes the magnetic design of the helical undulator coil.
- The effect of various construction errors on the undulator field profile is presented in detail.

Relevant Parameters

- Peak field on axis = 1 mT
- Undulator period = 80 mm
- Coil inner diameter = 80 mm
- Total length ~ 80 meters
- Construction unit length ~ 3 meters
- For electron energy of 54.34 MeV:
  - Electron beam angular deviation amplitude = ±70 μrad
  - Electron beam oscillation amplitude = 0.9 μm
- Angular deviation of electron beam, averaged over one period length, should be < 5 μrad (tentative).

Basic Design of the Undulator Coil

- Two helices, half pitch apart; equal and opposite currents.
- 80 mm pitch; 80 mm inner dia.
- 12 mm x 12 mm water cooled Cu conductor.
- 396 A needed for 1 mT field on axis.
- 3.8 A/mm^2 in Cu with a 7 mm dia. cooling channel. (2.8 A/mm^2 overall)



Other Components in the Magnet

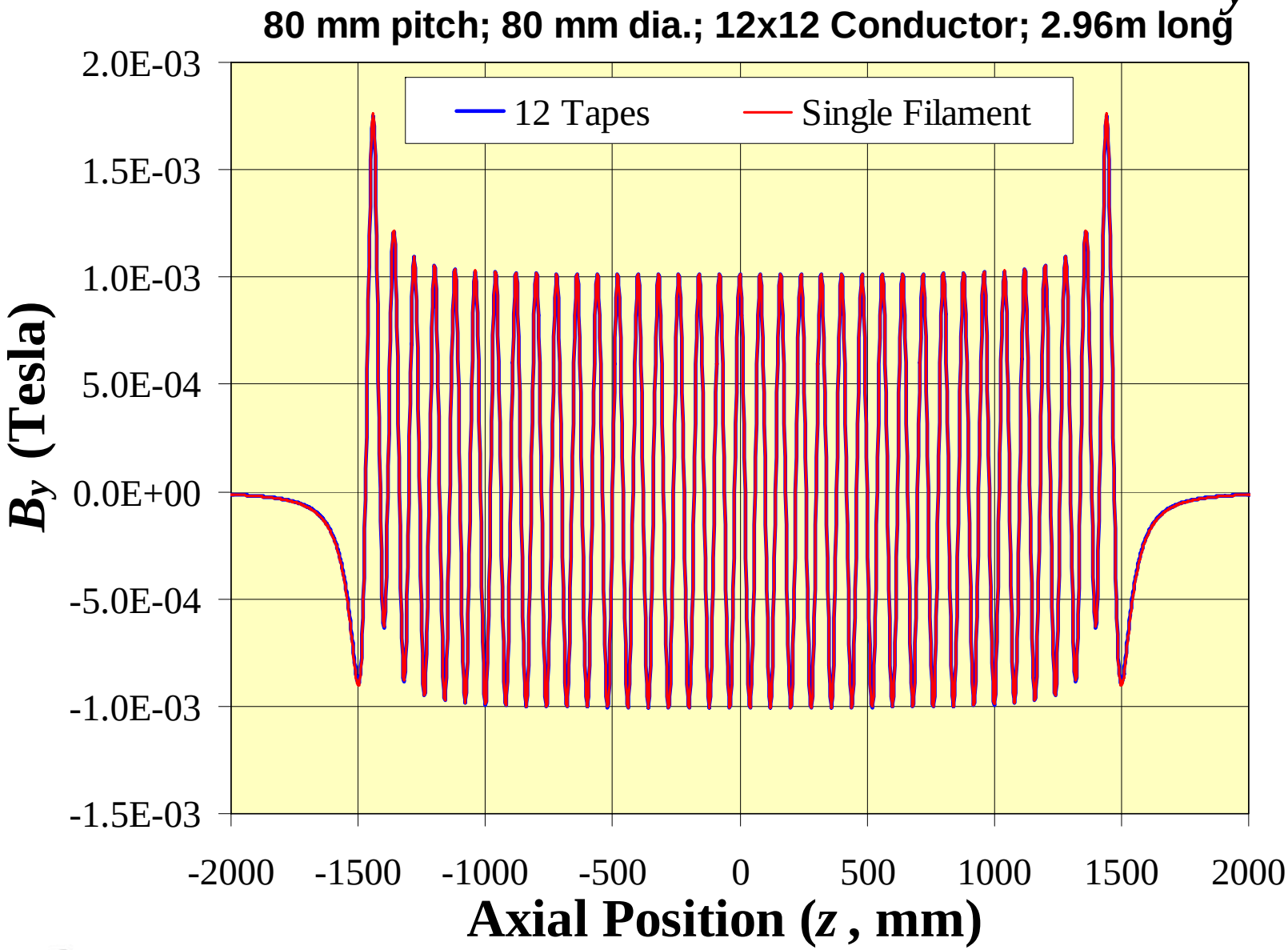
- Shielding of stray fields is very important:
  - Earth's field ~ 50 μT causes large bending
  - For low fields, Mu-metal shielding is most efficient.
  - Shield thickness depends on shield diameter, and is not finalized yet.
- Dipole Correctors:
  - Needed at the ends to compensate for end fields.
  - ***May*** be needed throughout the length of the undulator to correct error fields (?).
  - Design of correctors is not finalized yet.

Computation of Field Profile

- Perfect geometry using Opera-3D (Ramesh Gupta)
  - Difficult to model various construction errors
- Numerical integration and Biot-Savart Law:
  - Special code for helical thin tapes:
    (12 layers of 12 mm wide tapes; perfect construction; alignment errors can be studied.)
  - Conductor replaced by a single filament:
    (Good reproduction of field profile after slightly adjusting radius and current; a variety of construction errors are easy to model.)
- Models with 37 turns in each helix (2.96 m long)

Computed Field Profile On-axis (B_x)

Computed Field Profile On-axis (B_y)



Evaluating On-axis Field Quality

- Primary requirement is to keep the electron direction parallel to the ion beam direction, on an average over one undulator period.
- The angular deviation at any axial position is:

$$\sin\theta_{x,y} = \left(\frac{c}{V}\right)\frac{1}{\left[1+2(V_0/V)\right]^{1/2}}\int_{-\infty}^{z} B_{y,x}(z)dz$$

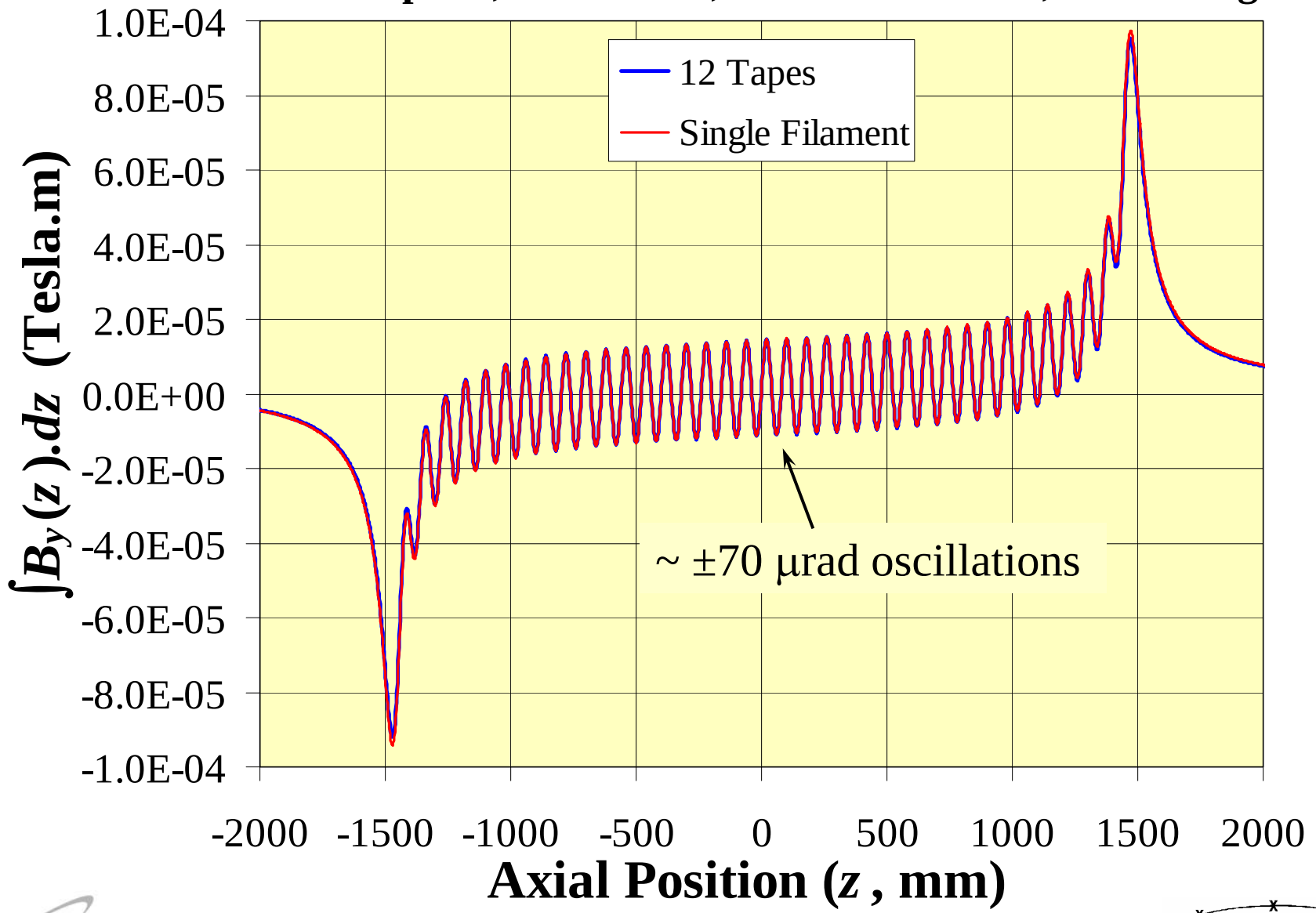
(V_0 = rest mass in eV, V = energy in eV)

$$= 5.47 \times \left[\int_{-\infty}^{z} B_{y,x}(z)dz \text{ in T.m}\right] \text{ for 54.34 MeV electrons}$$

- Integral of B_y (or B_x) should be < ~1×10^{-6} T.m for $\theta_{x,y} < 5$ μrad.

Computed Field Integral On-axis

80 mm pitch; 80 mm dia.; 12x12 Conductor; 2.96m long



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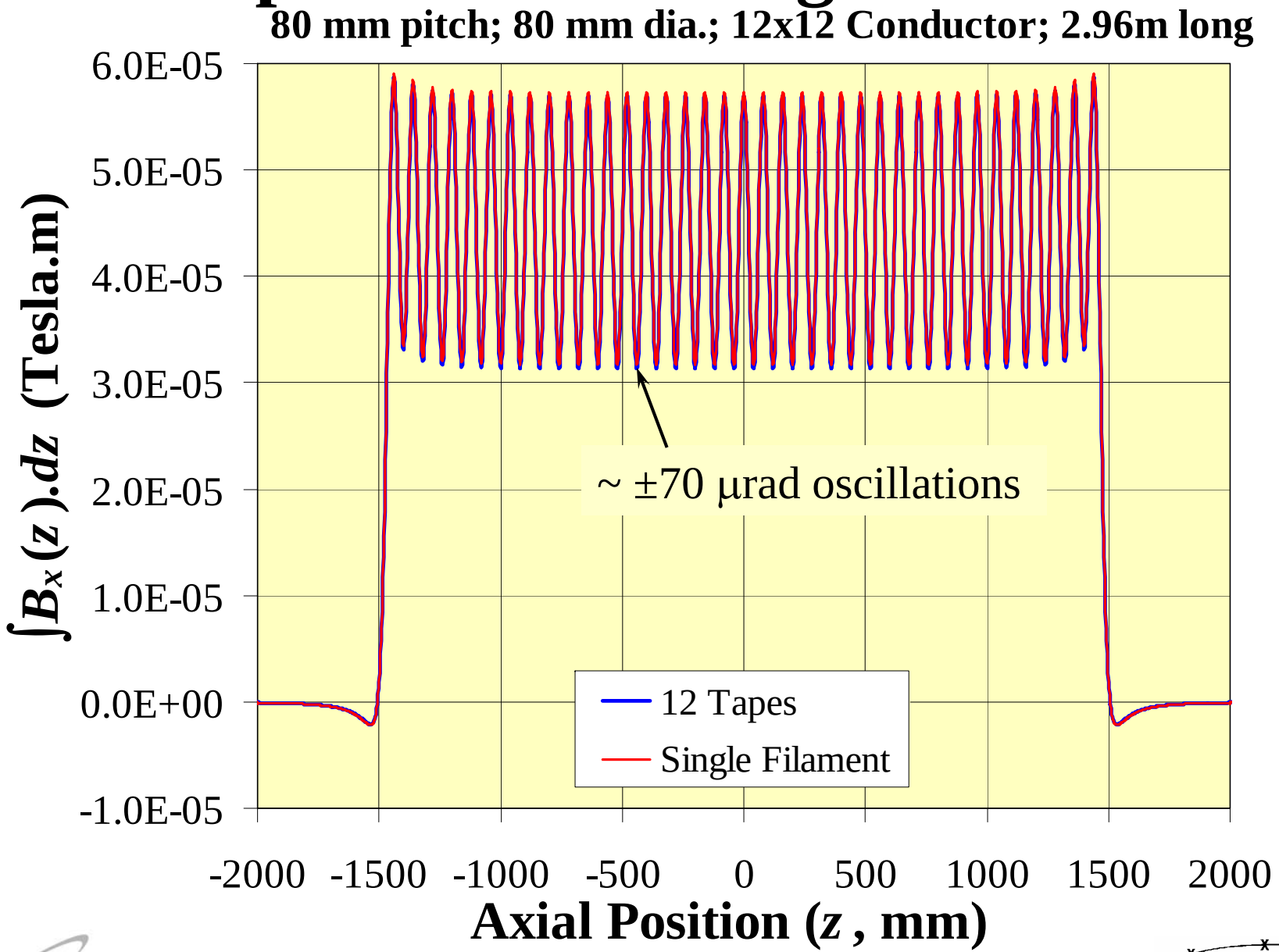
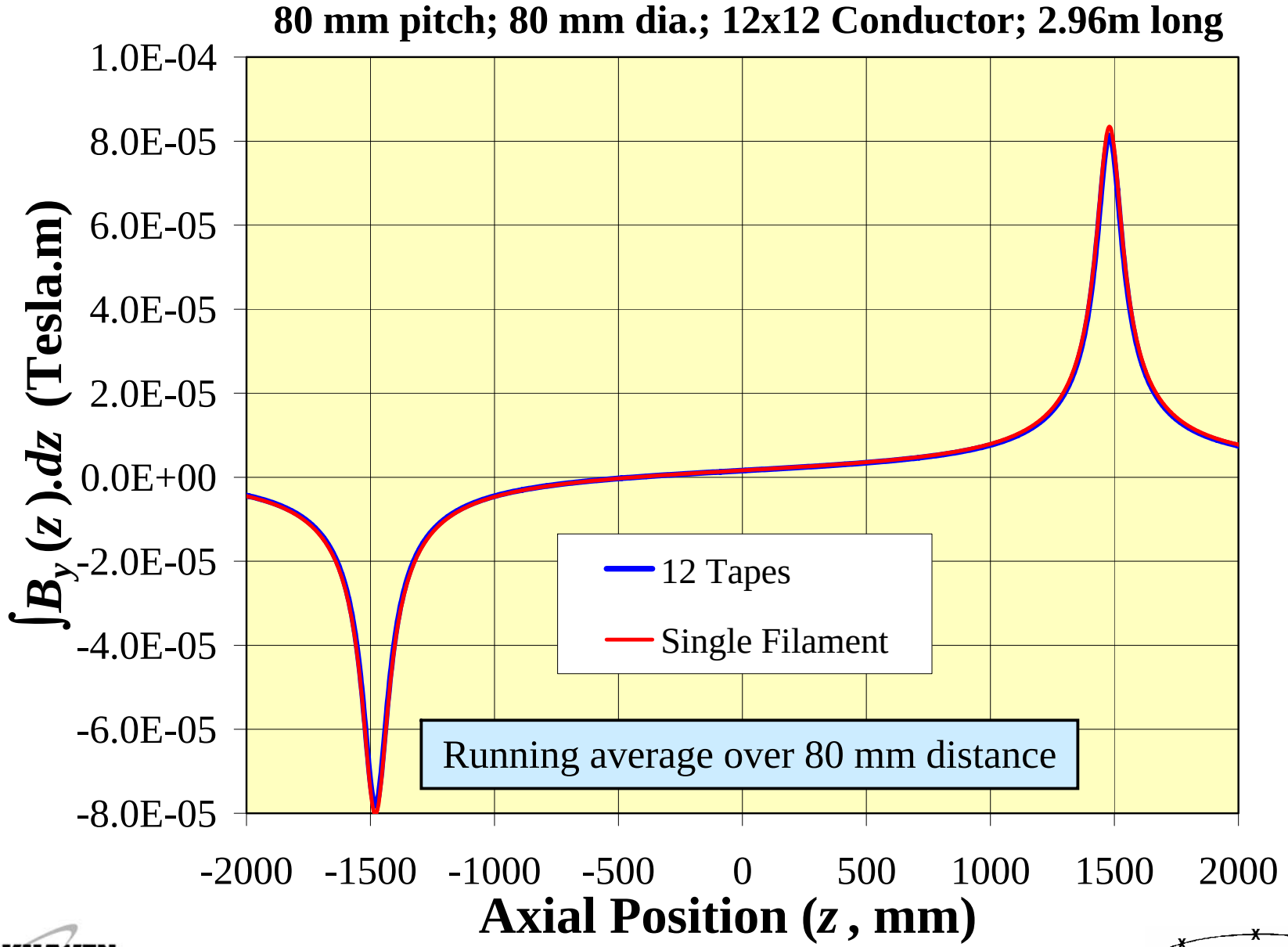


Field Integral On-axis (80 mm Avg.)



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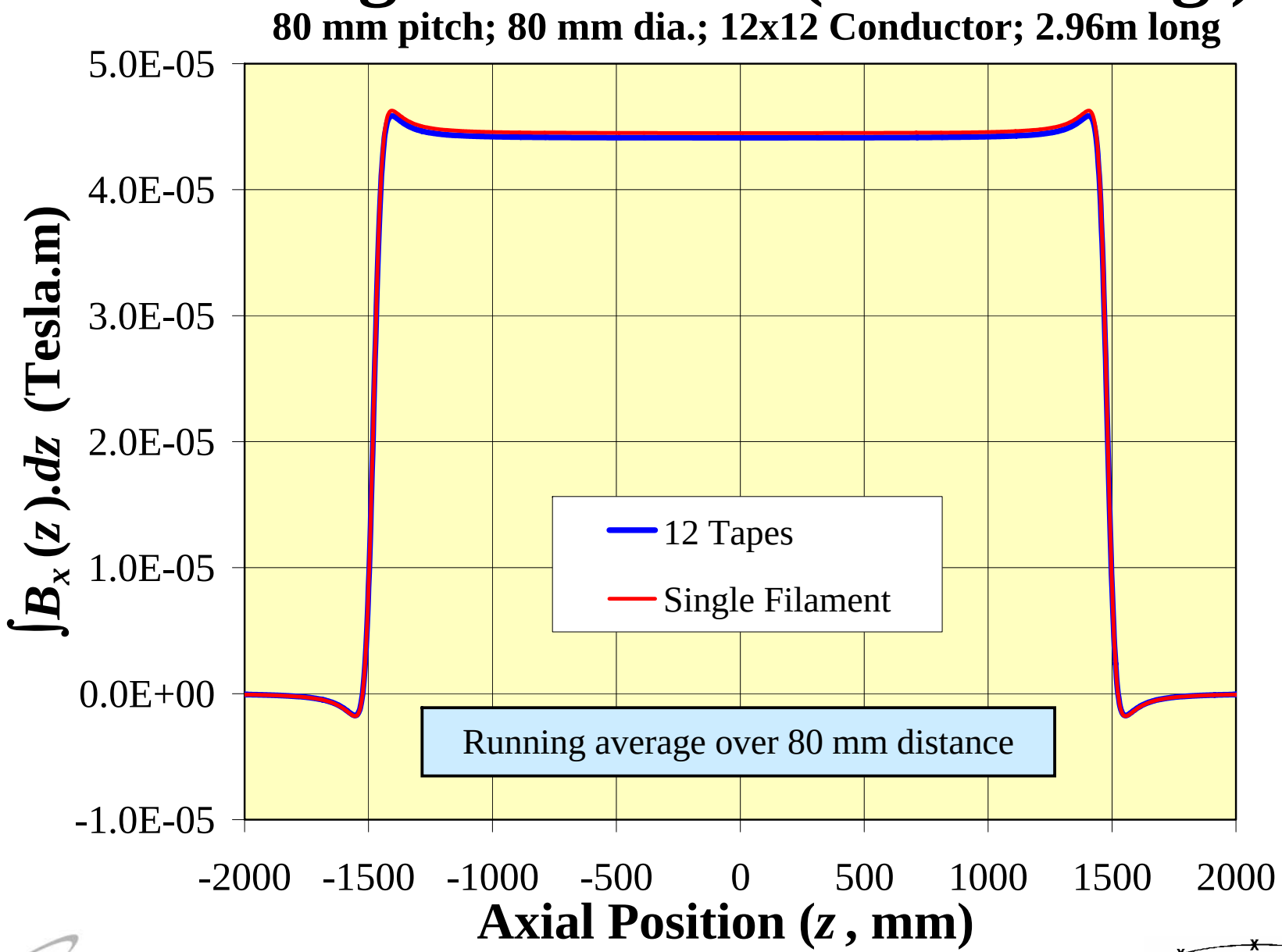
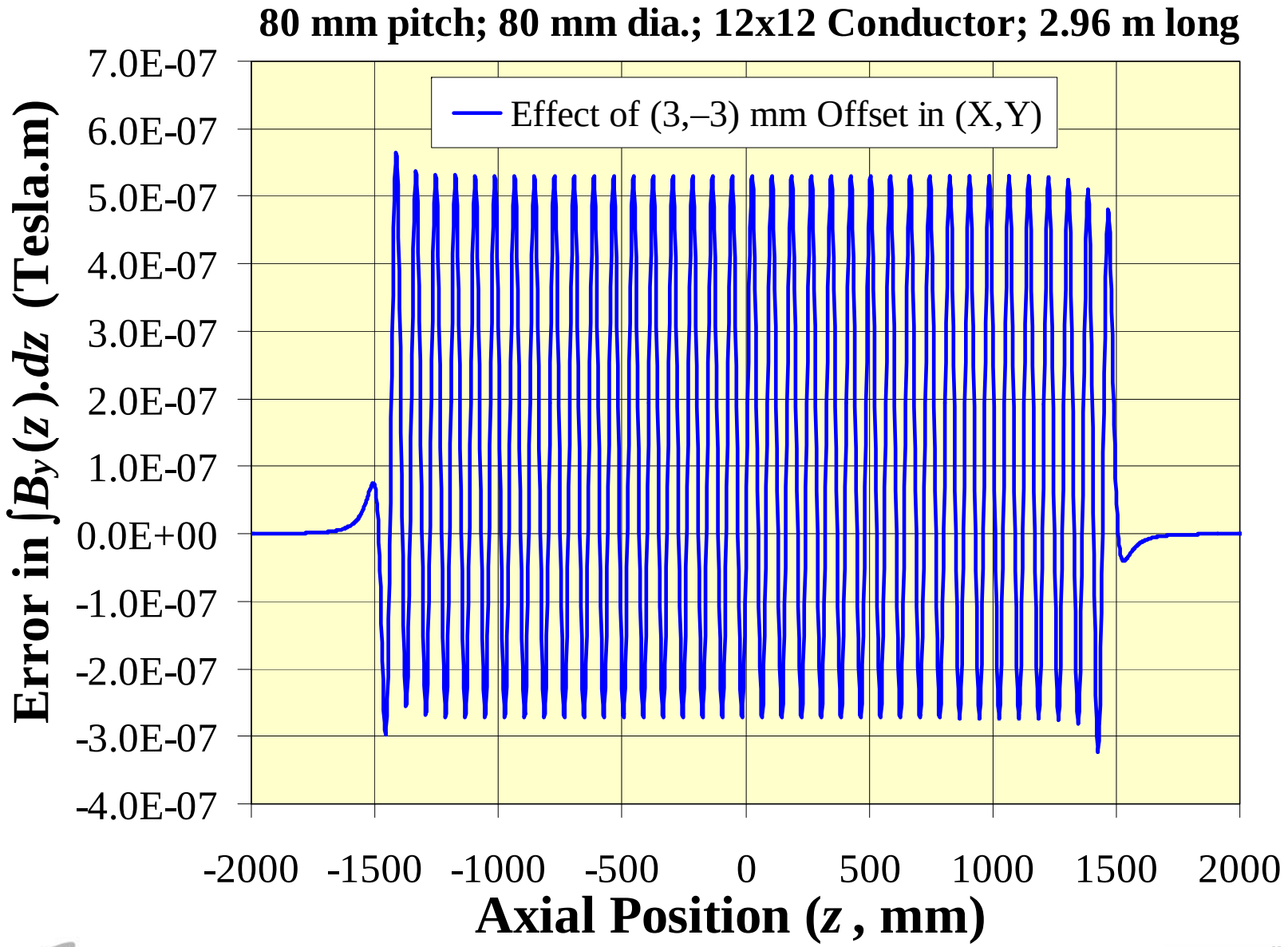


Alignment and Construction Errors

- Offset of beam with respect to the geometric axis.
- Tilt of the beam axis relative to the geometric axis.
- Ovality of the coil support tube.
- Radius variations (slow) along the length.
- Pitch variations (slow) along the length.
- Random variations of radius and pitch with each turn, along with a tilt of the beam axis.
- Only the *error* in on-axis field profile due to a particular type of construction error will be shown.

Offset of Beam wrt Geometric Axis



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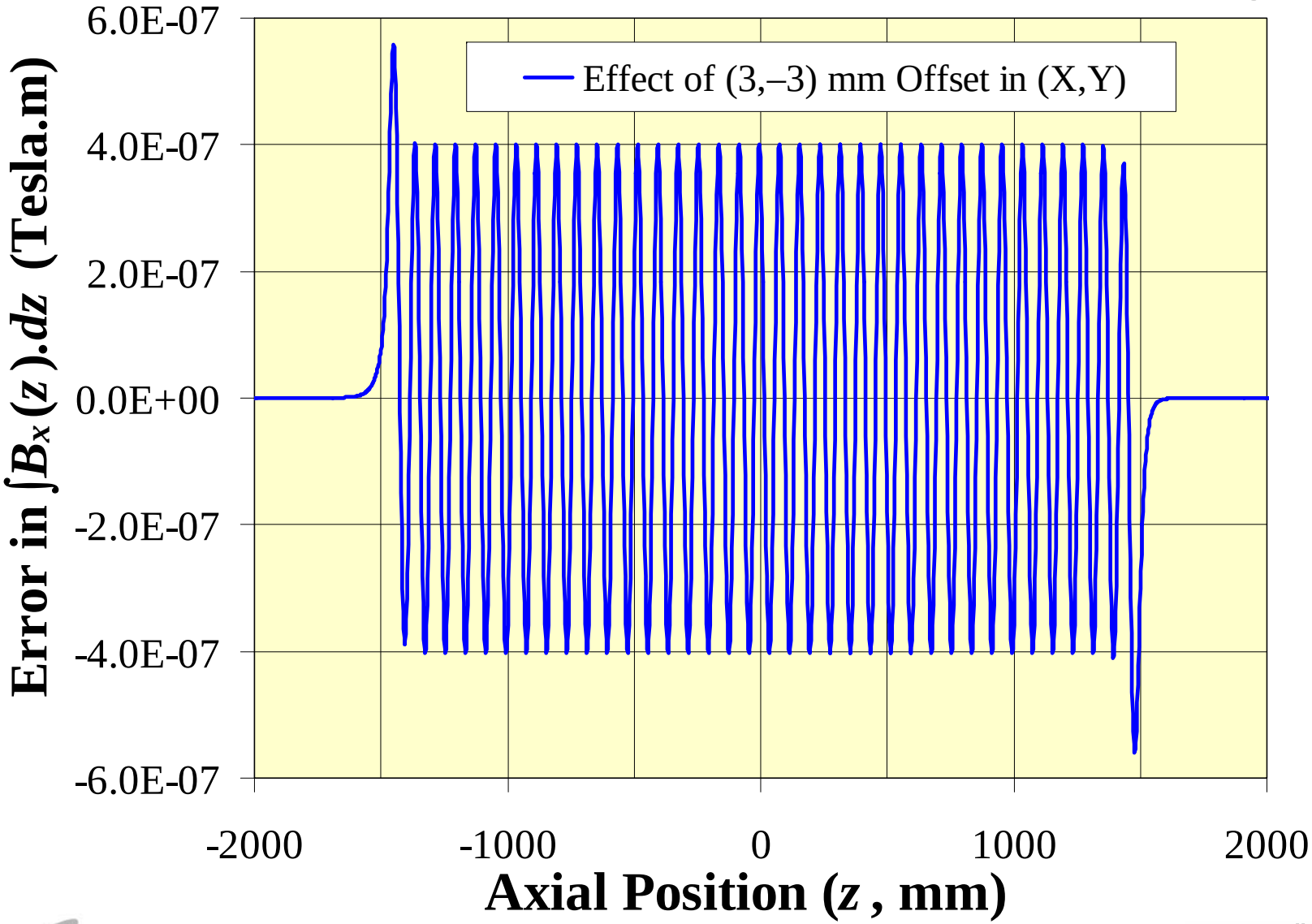

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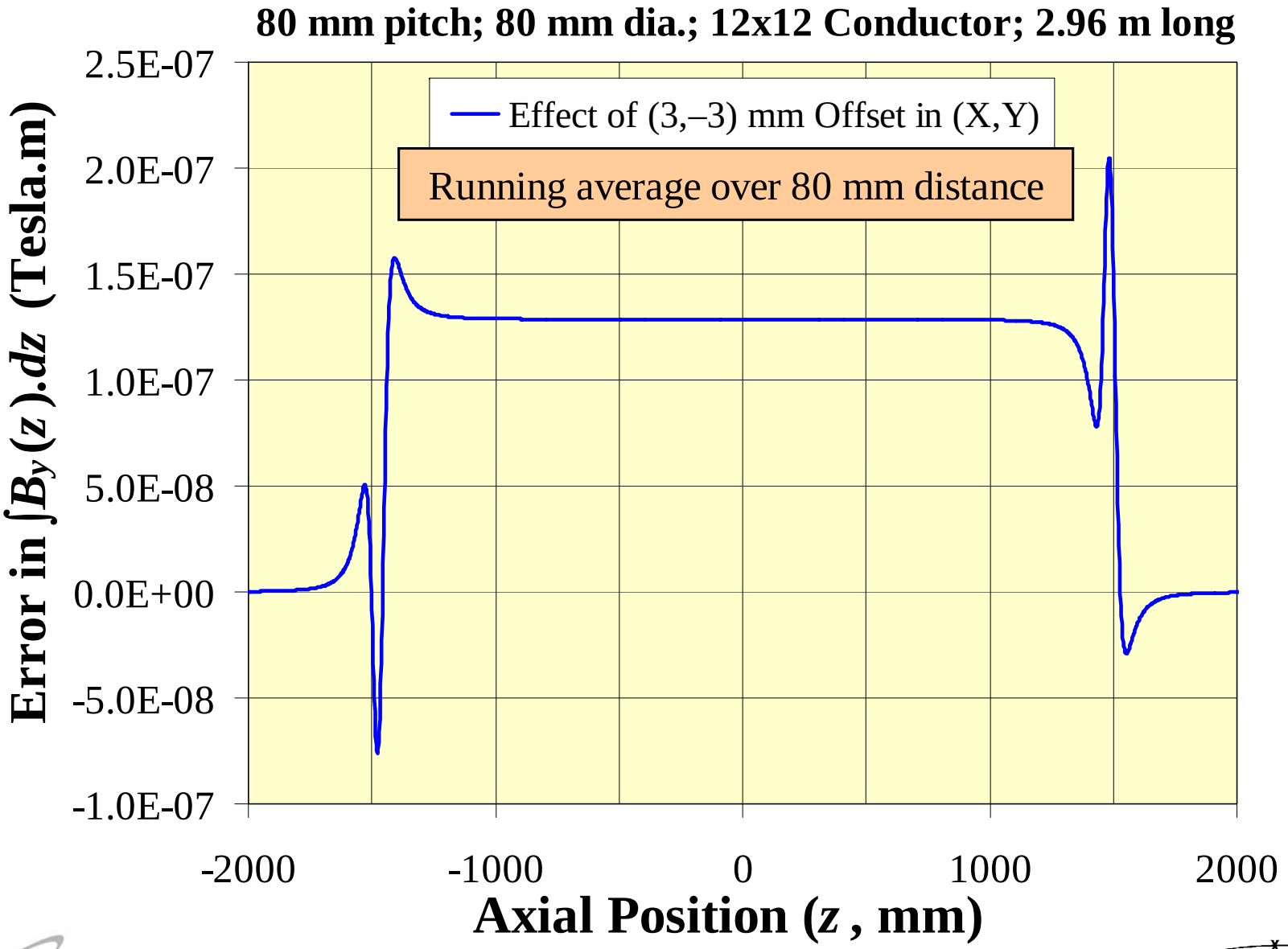

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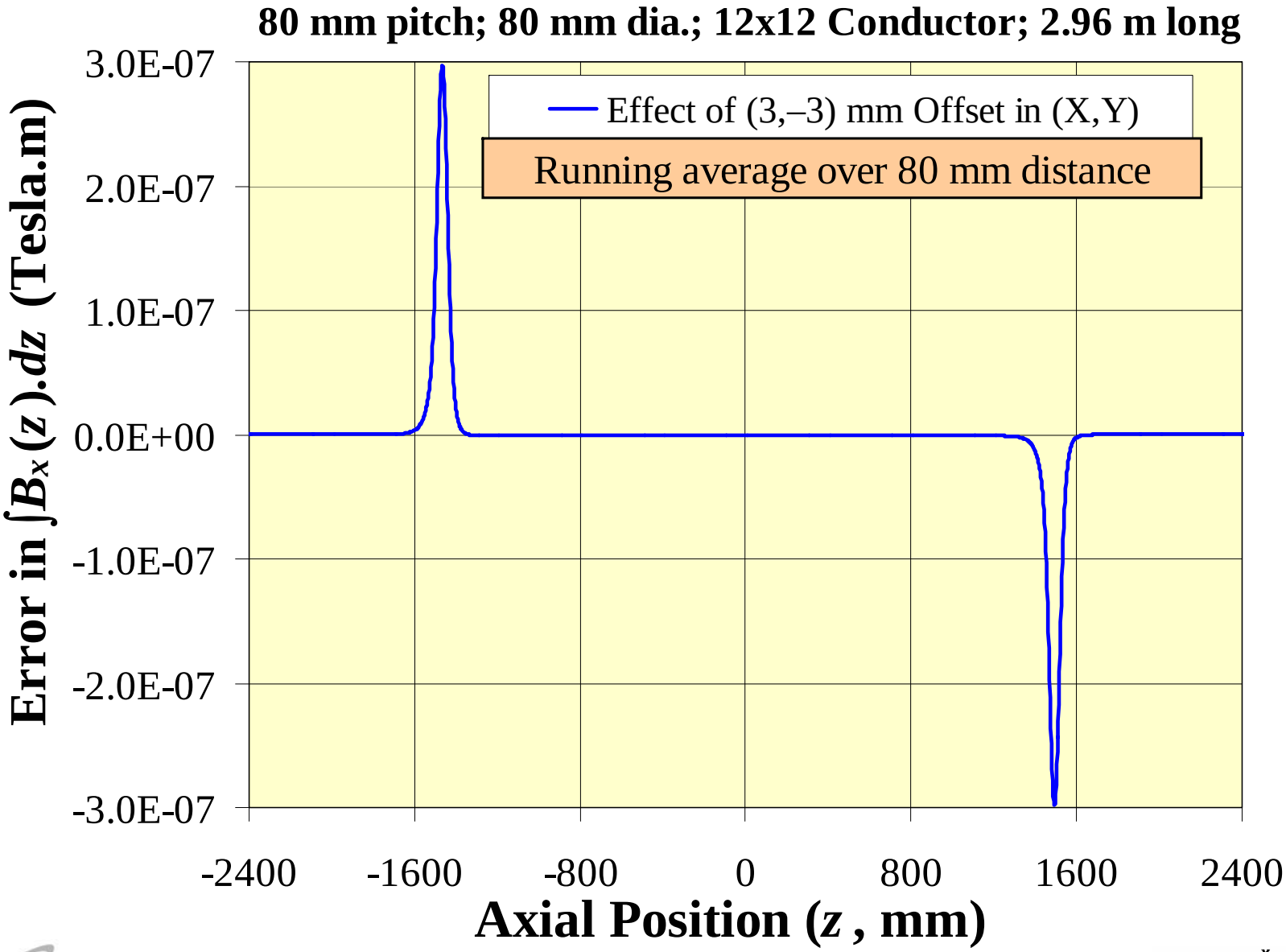
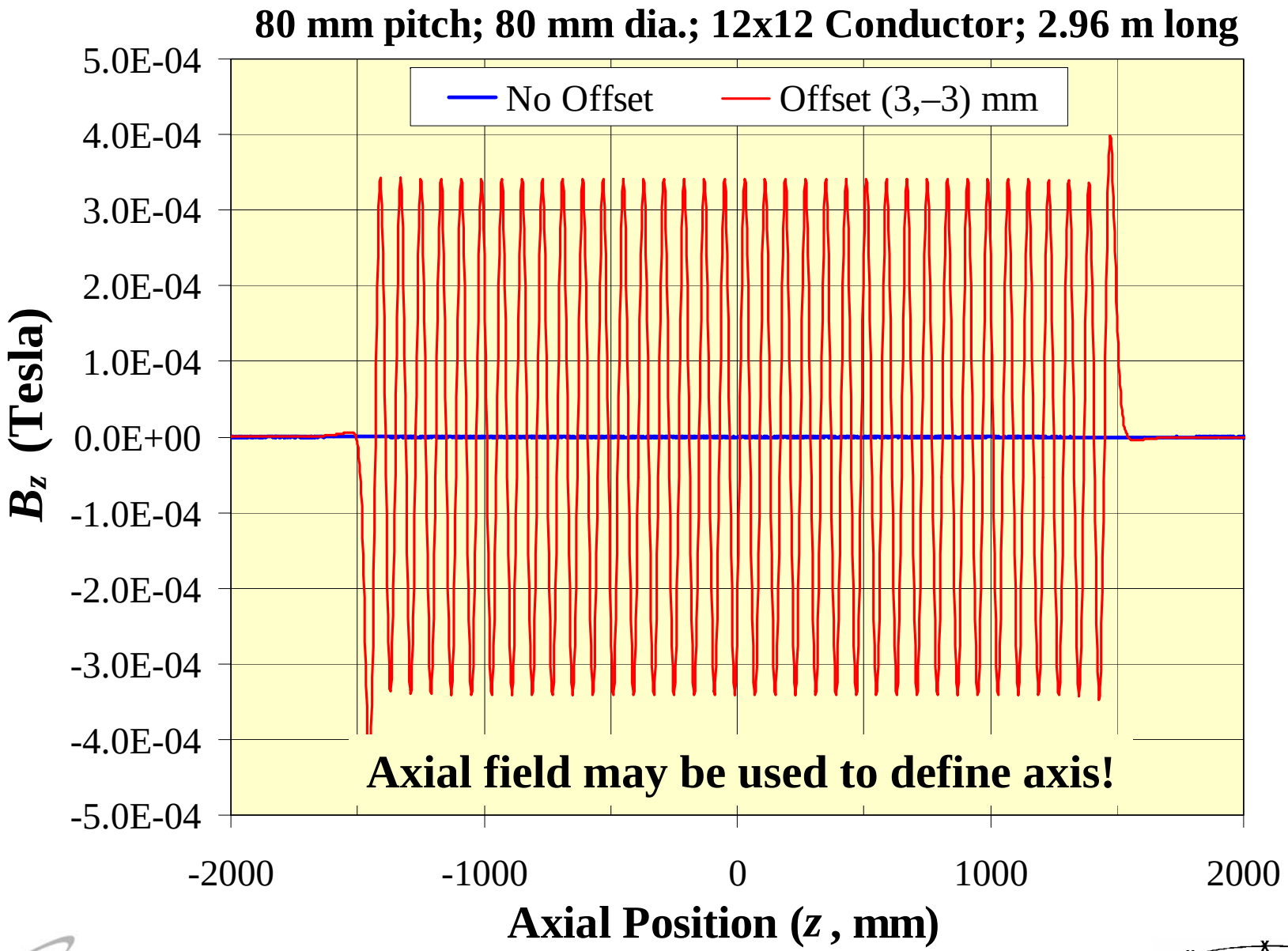
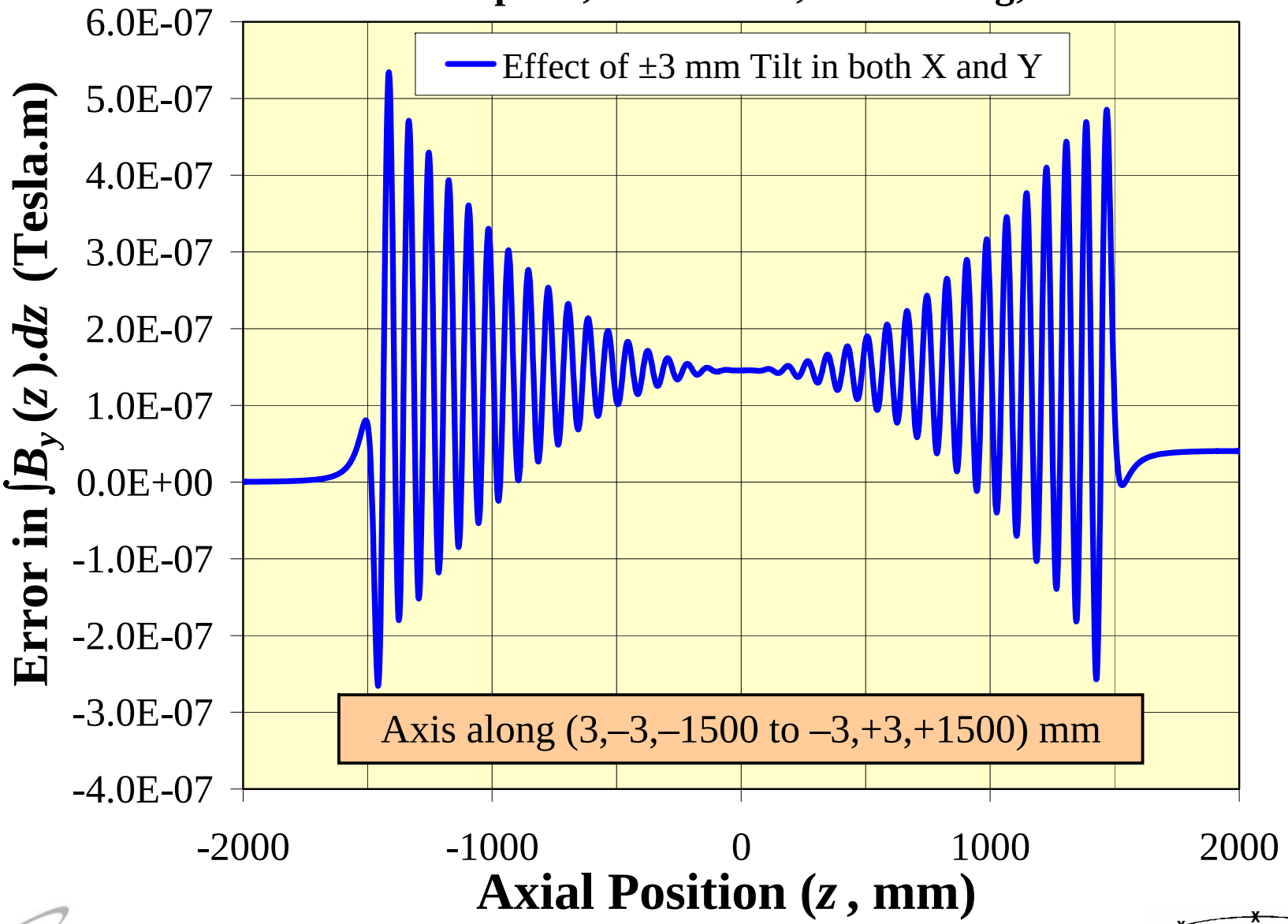


Offset of Beam: Axial Field Component



Tilt of Beam wrt Geometric Axis

80 mm pitch; 80 mm dia.; 2.96 m long; 396A



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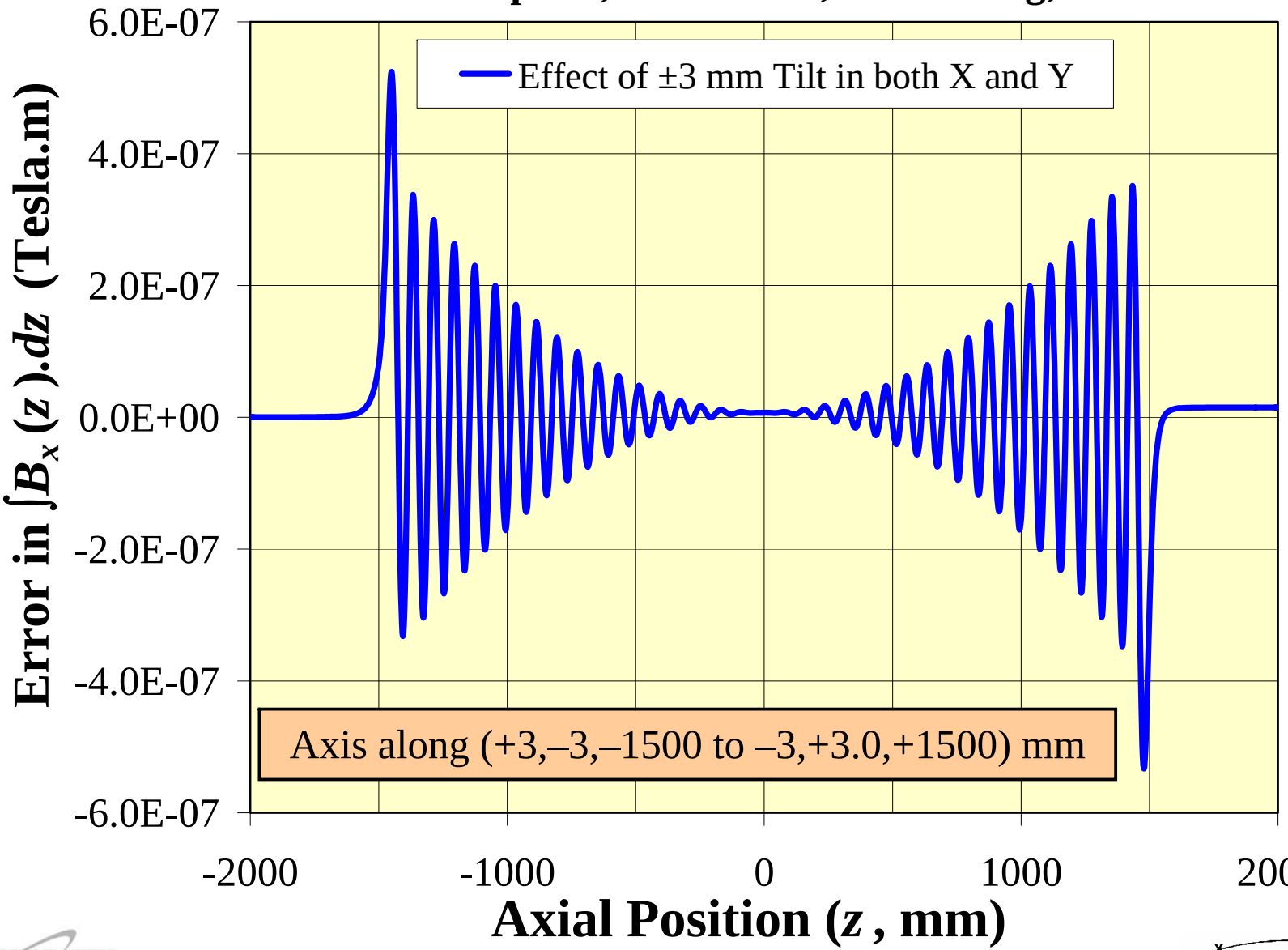

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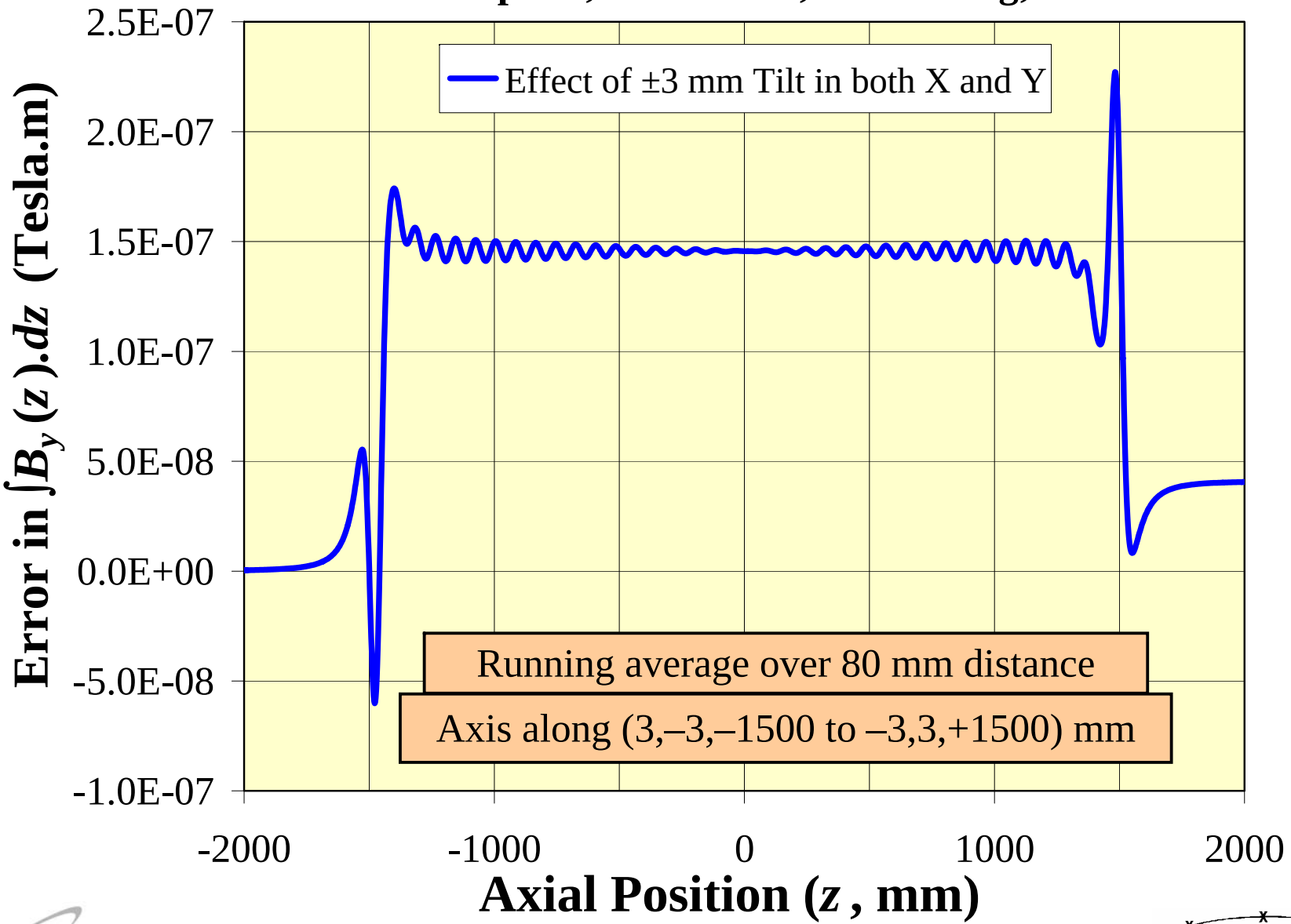

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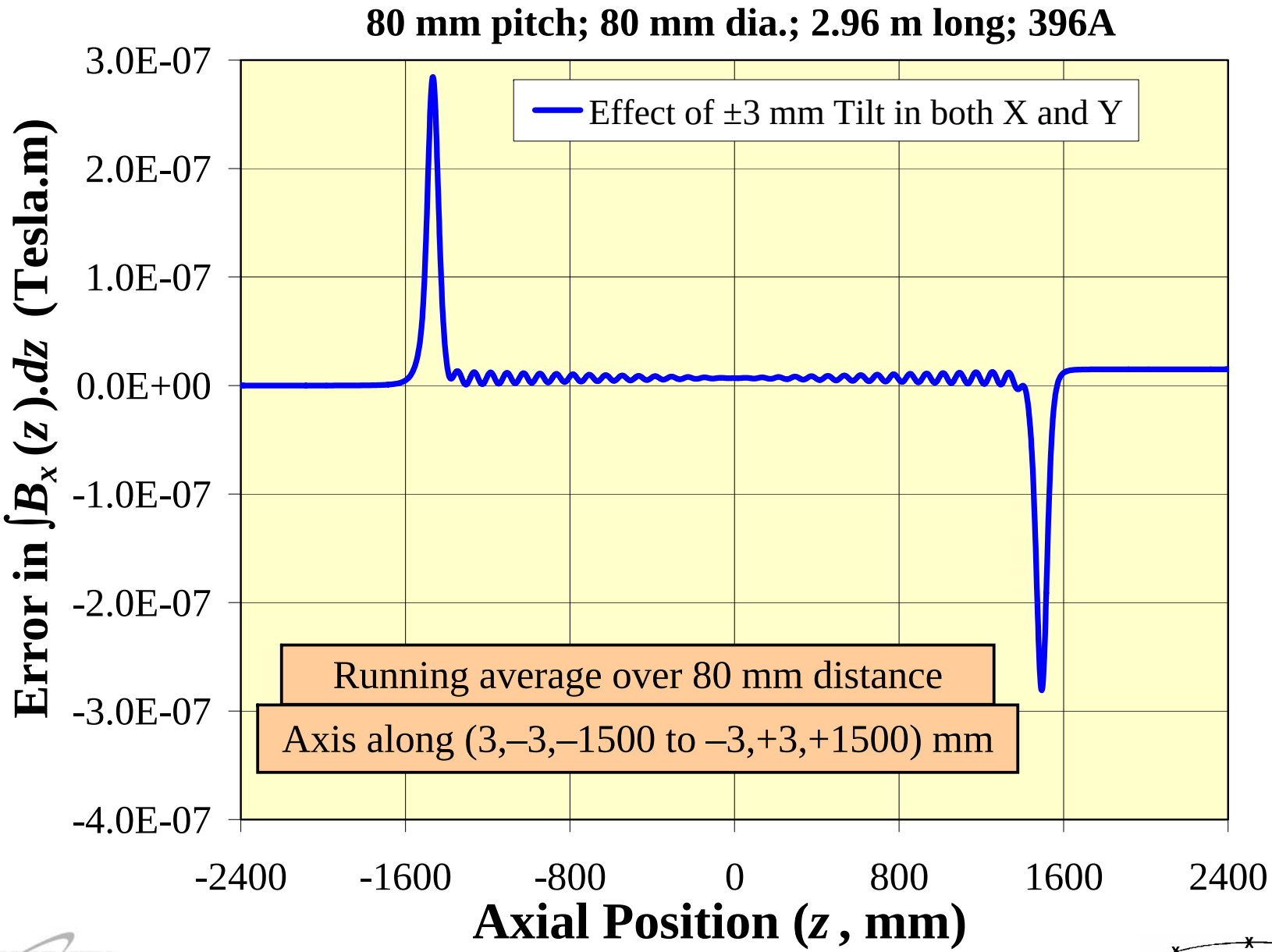
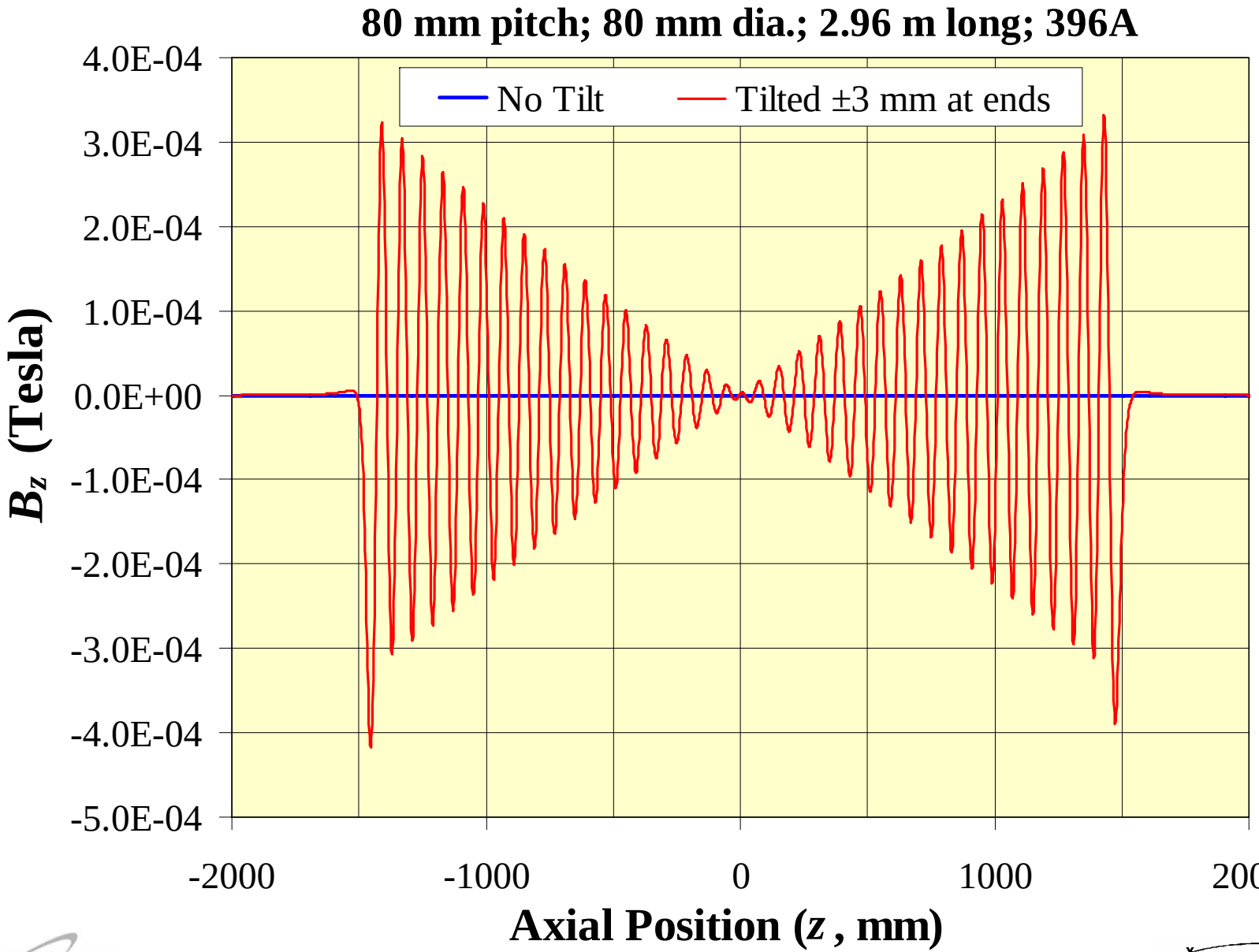
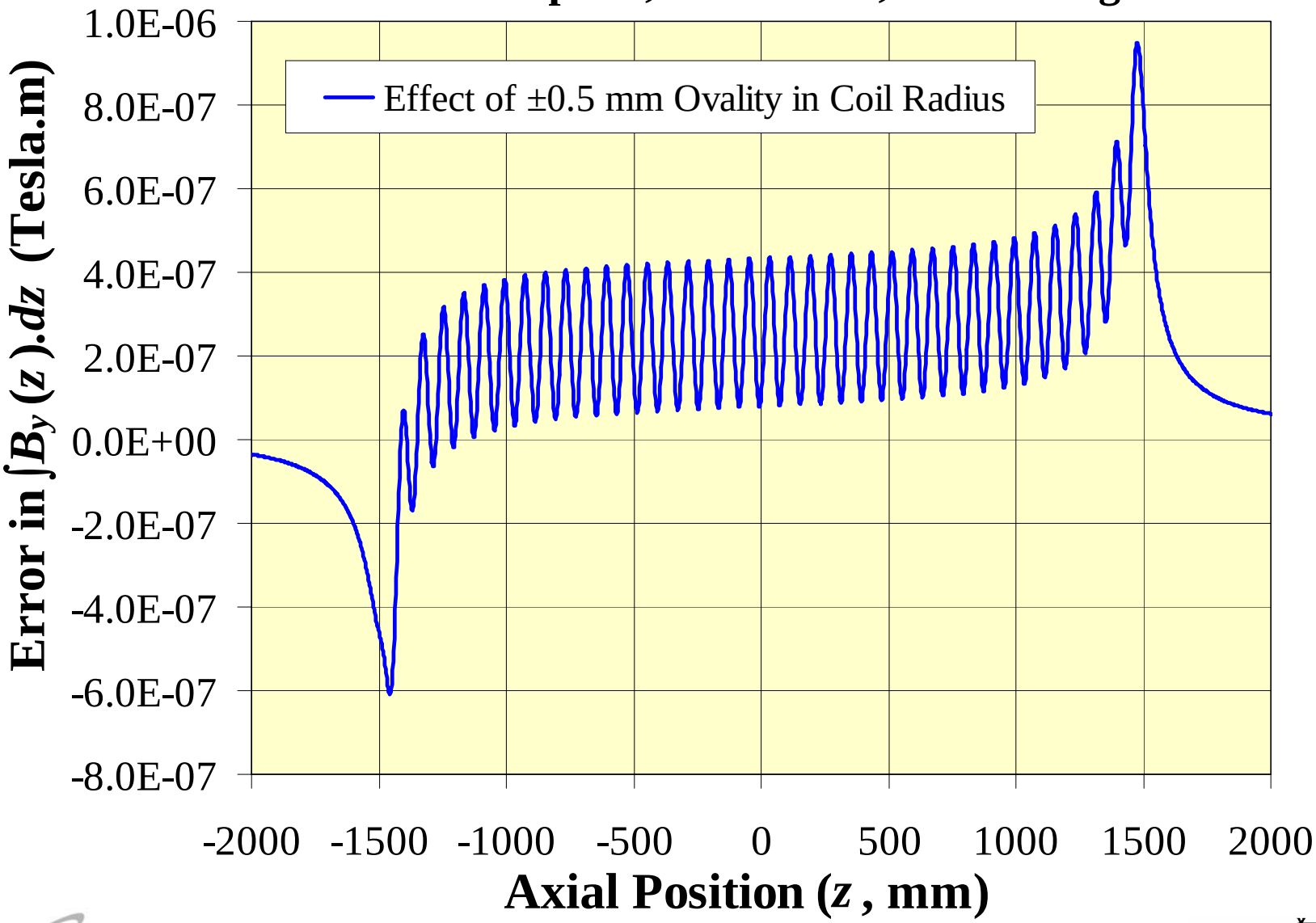


Tilt of Beam Axis: Axial Field Component



Elliptical Shape of Coil (R ± 0.5 mm)

80 mm pitch; 80 mm dia.; 2.96 m long



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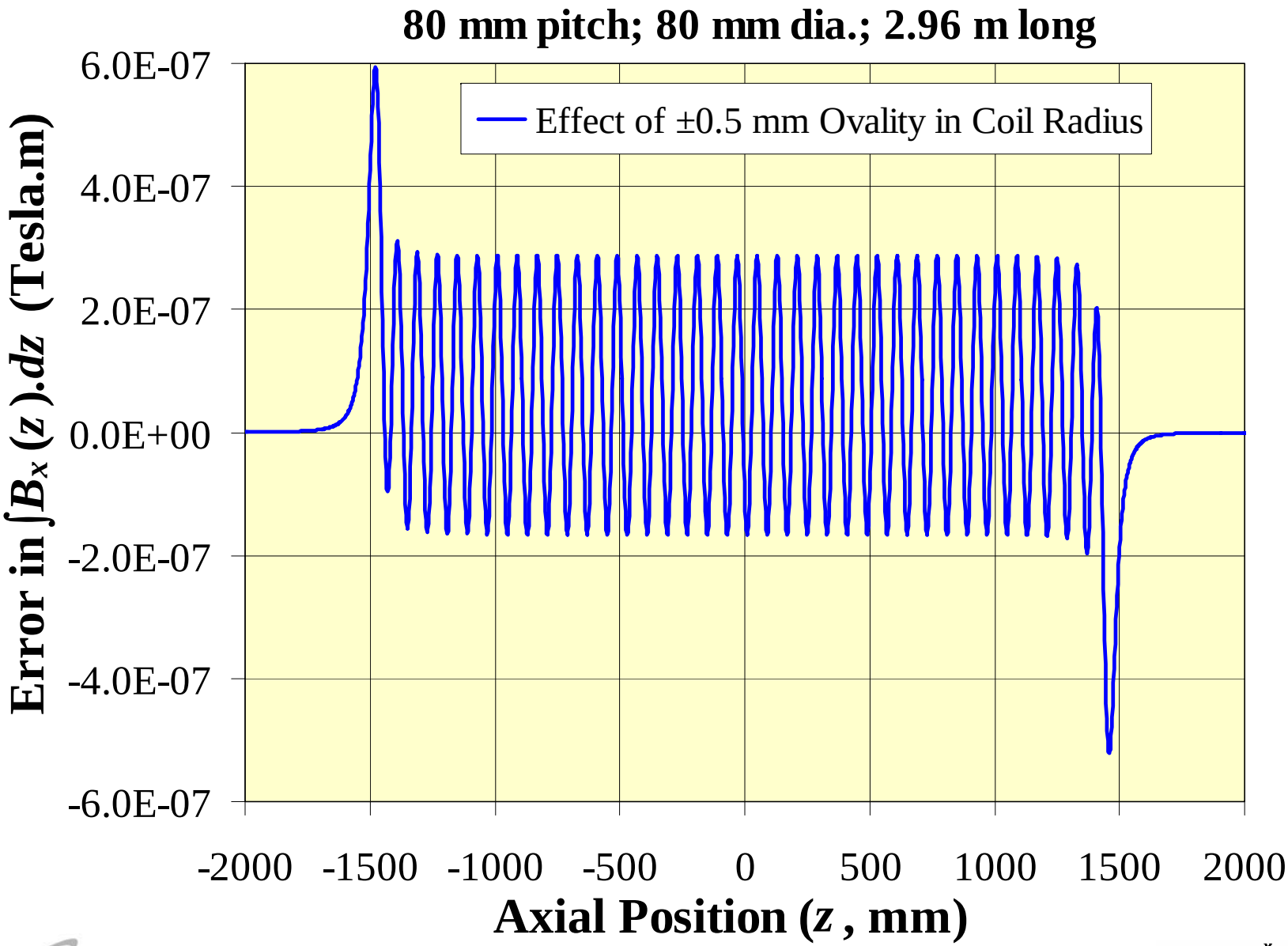

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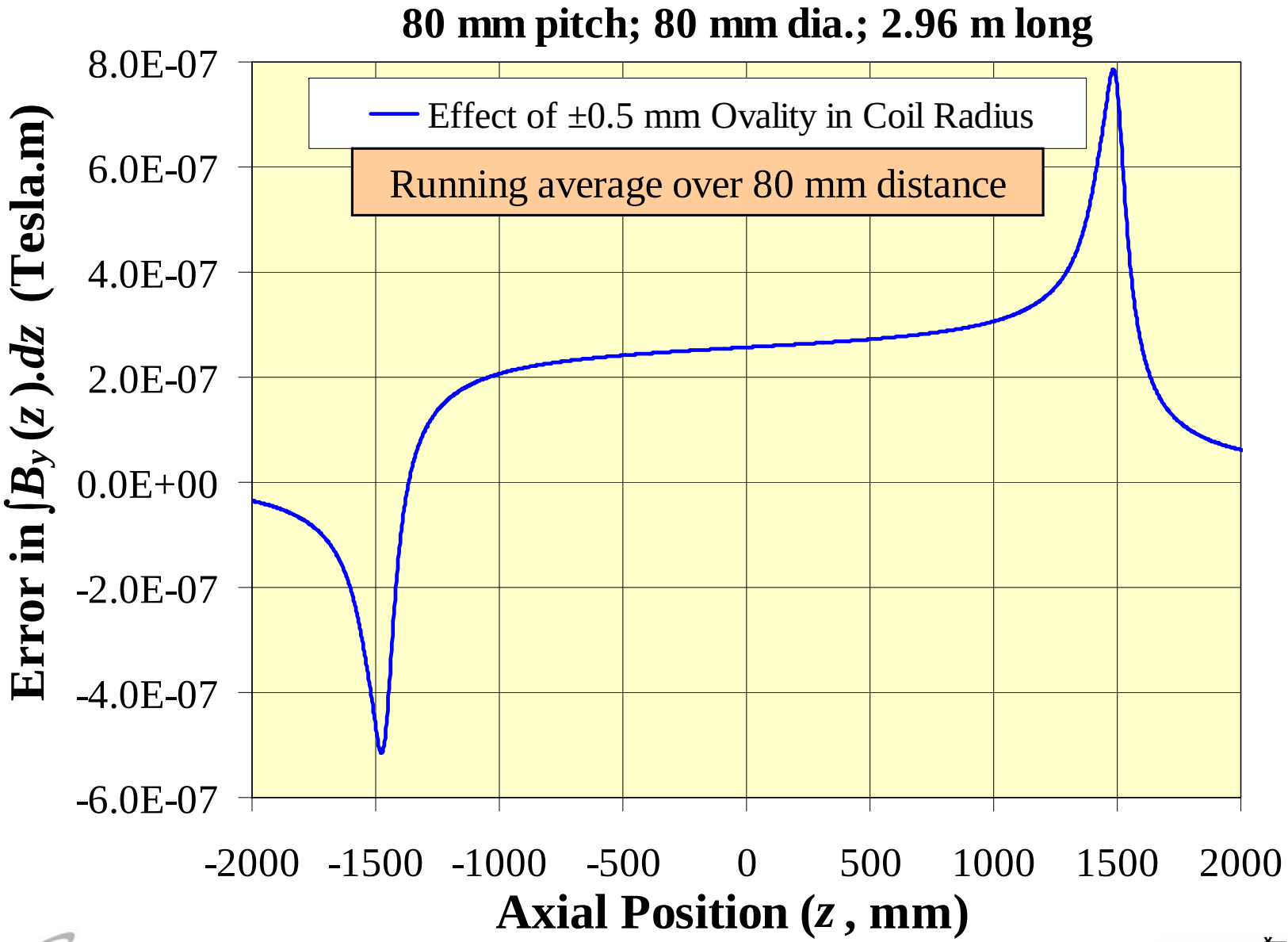

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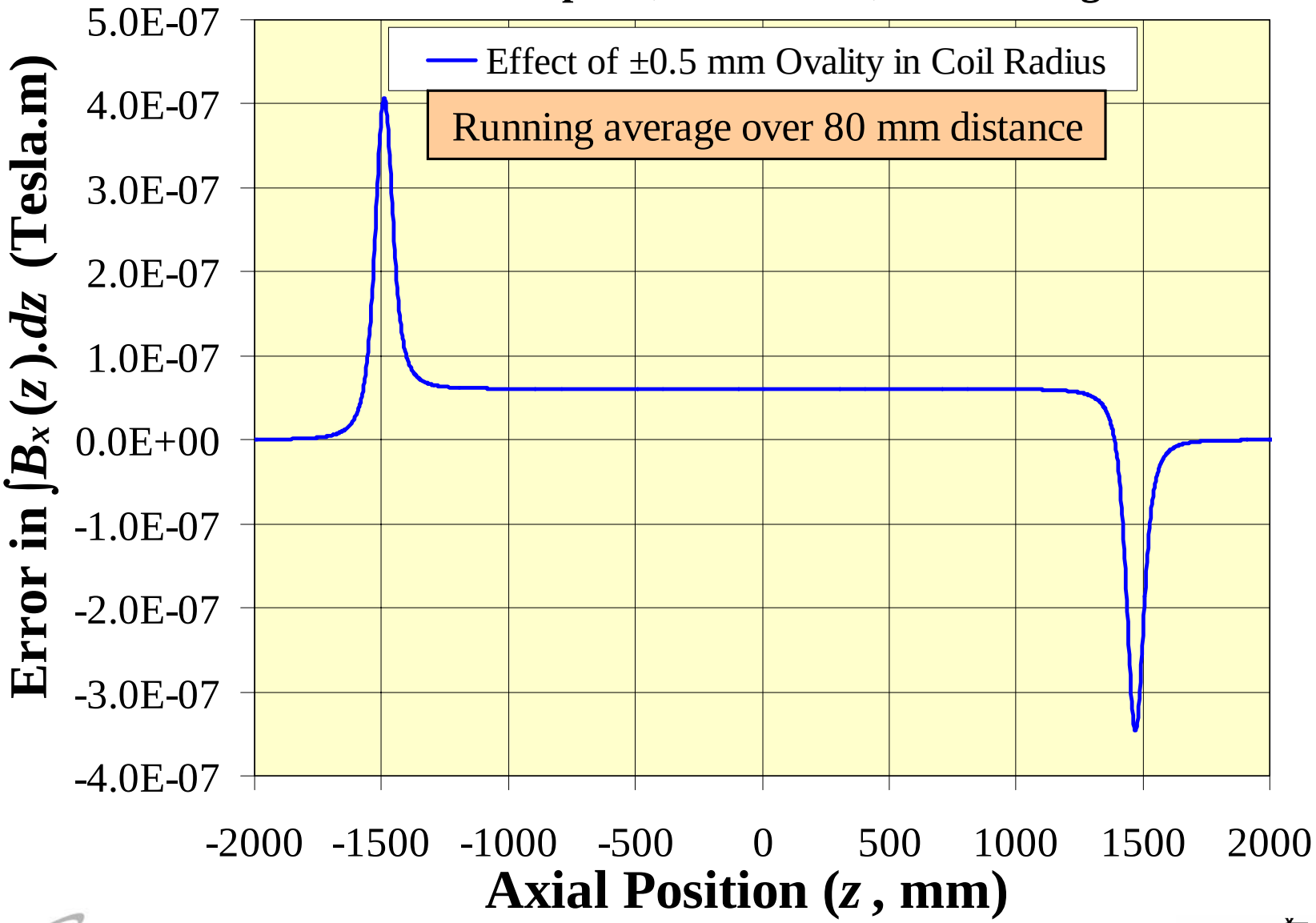
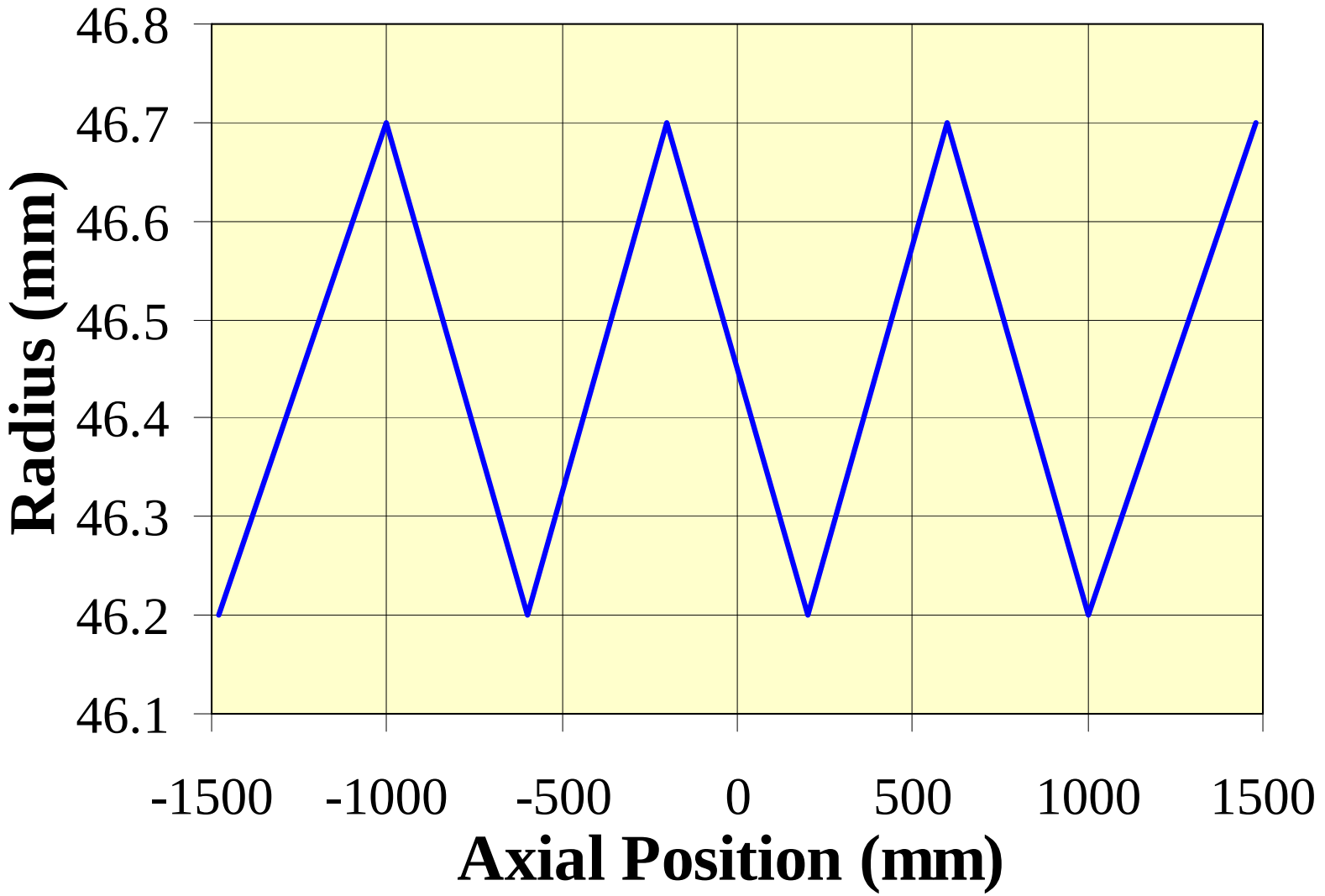


Radius Variation 0.5 mm over 5 to 6 Turns



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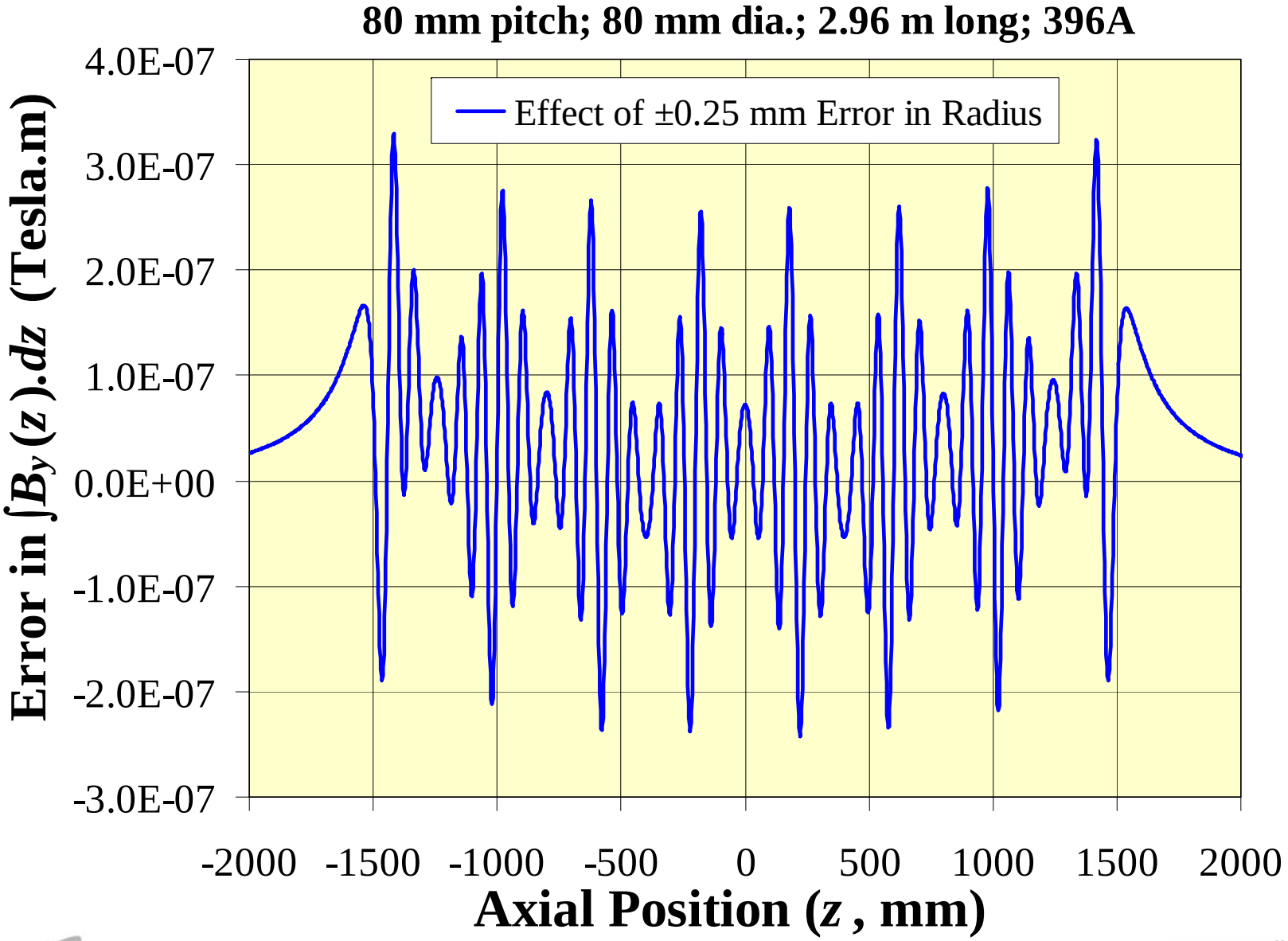

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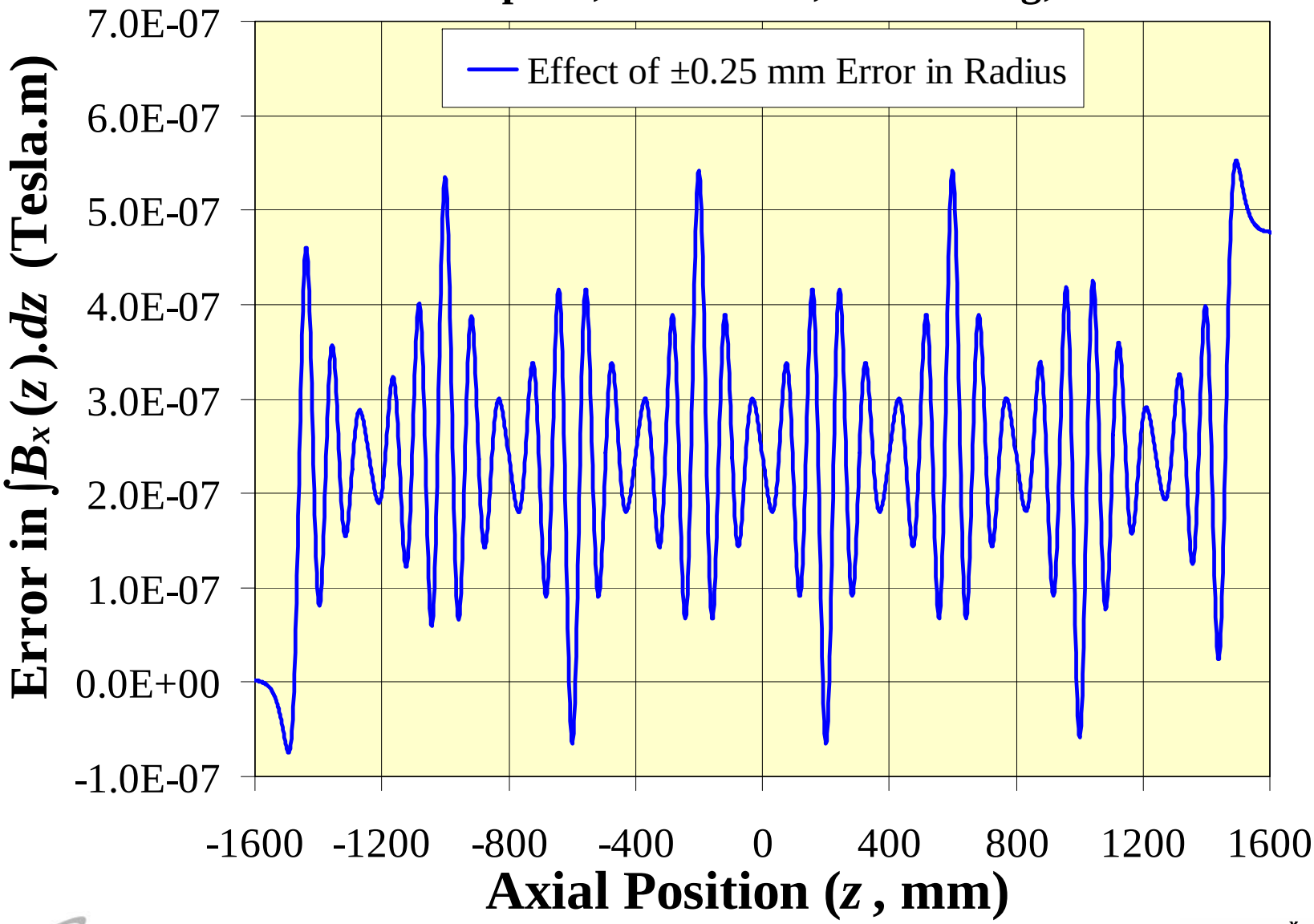

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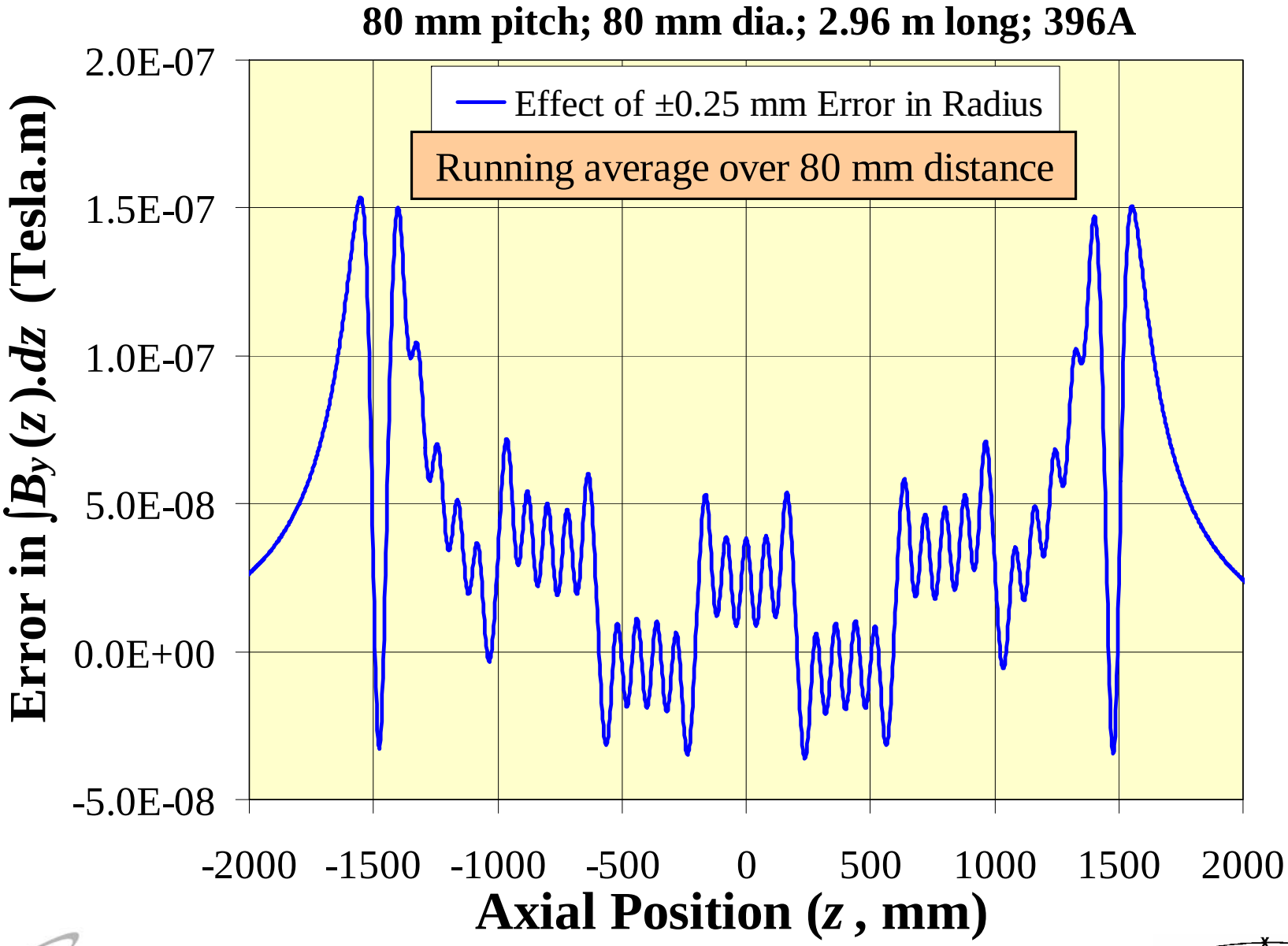

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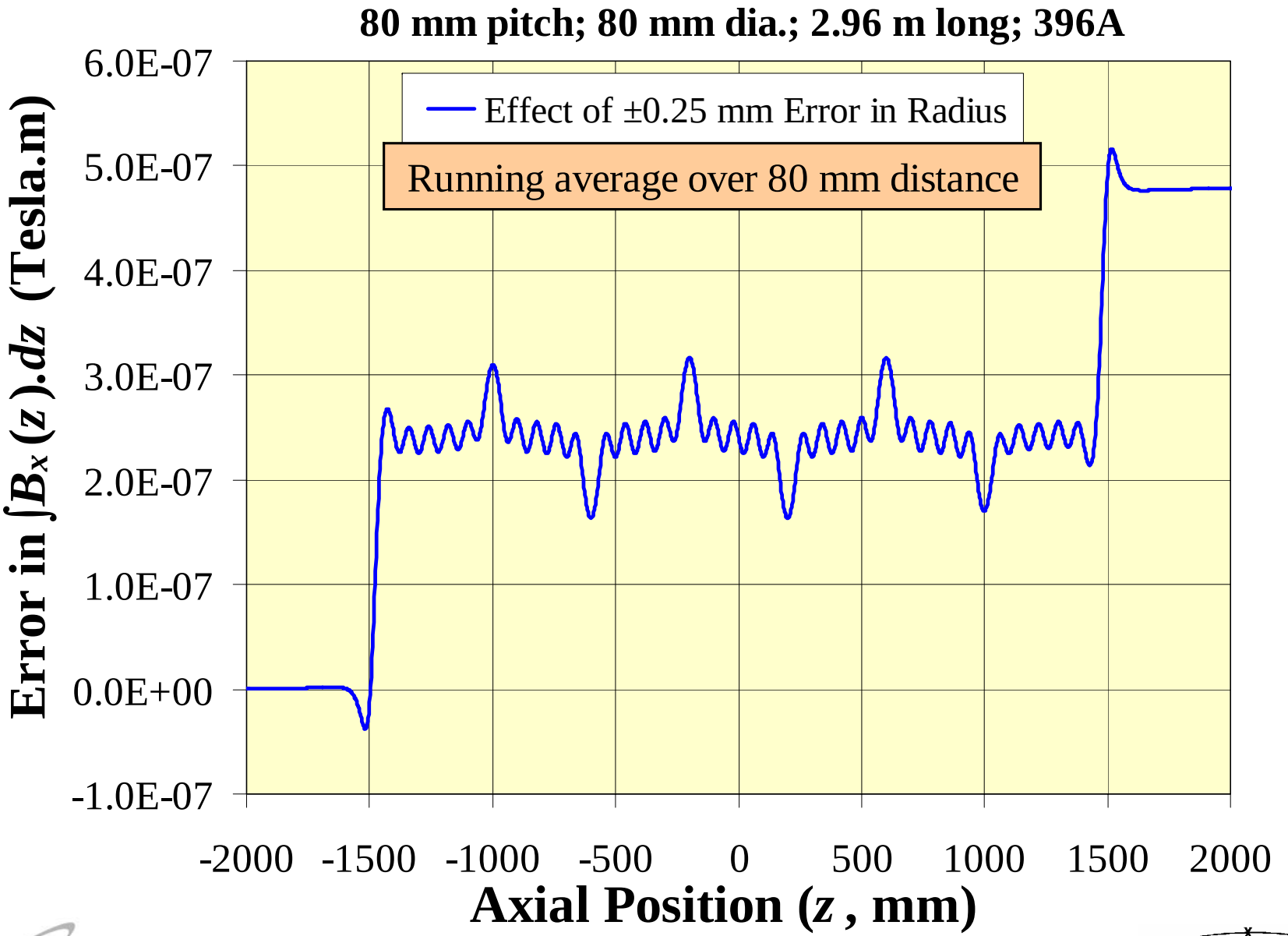
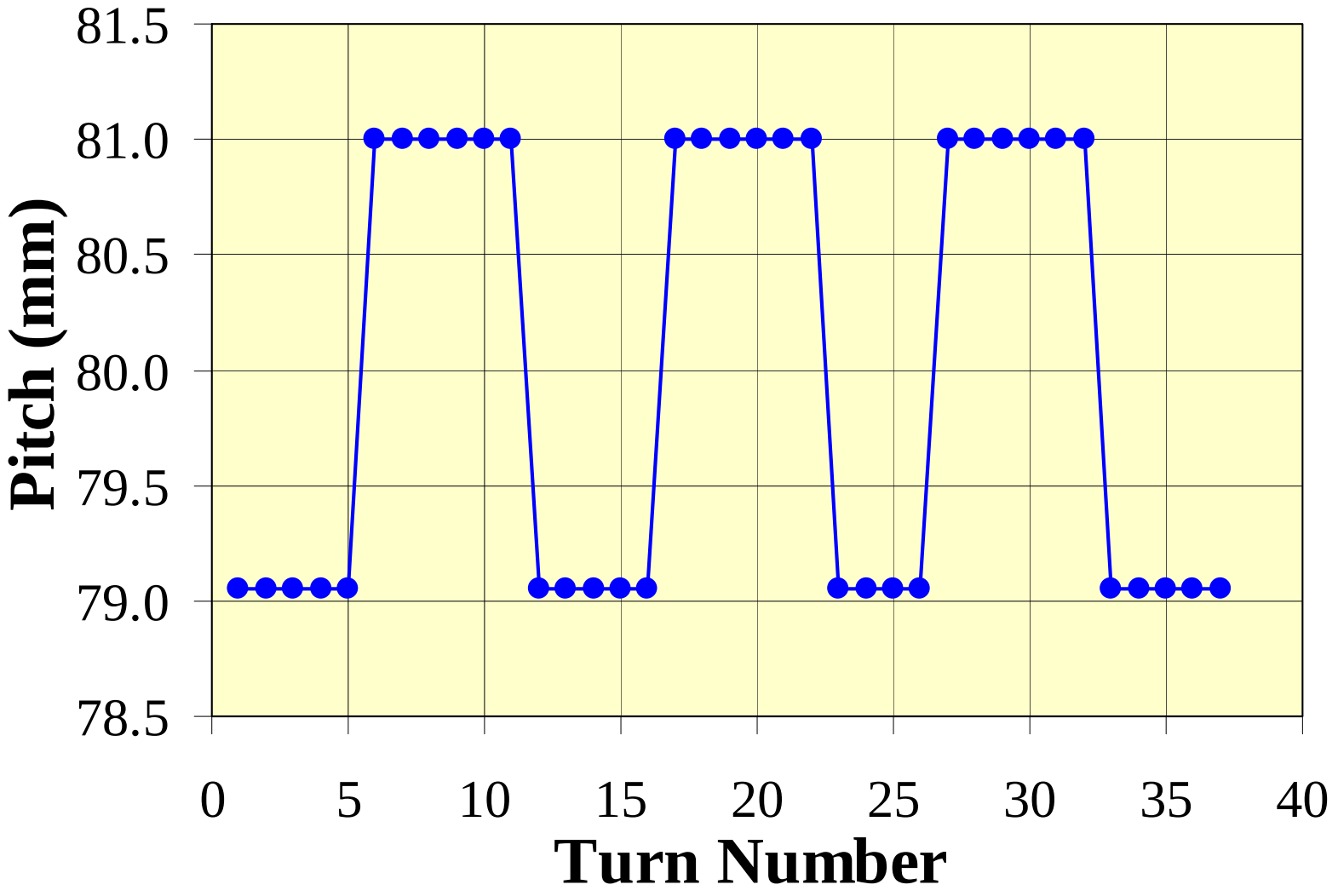
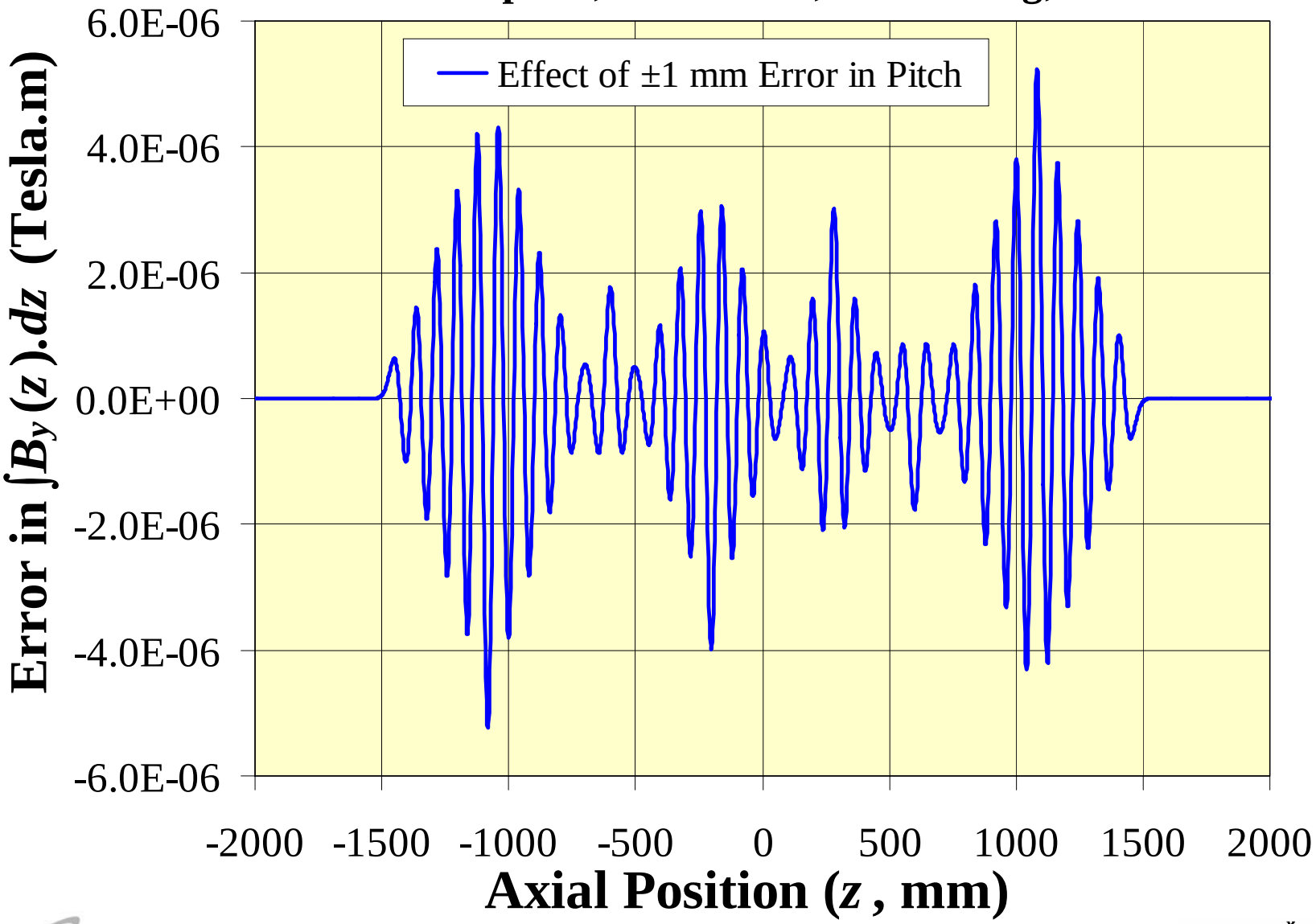


Pitch Errors: ~2 mm Jumps



Pitch ±1 mm in 4 to 6 Turn Segments

80 mm pitch; 80 mm dia.; 2.96 m long; 1 mT



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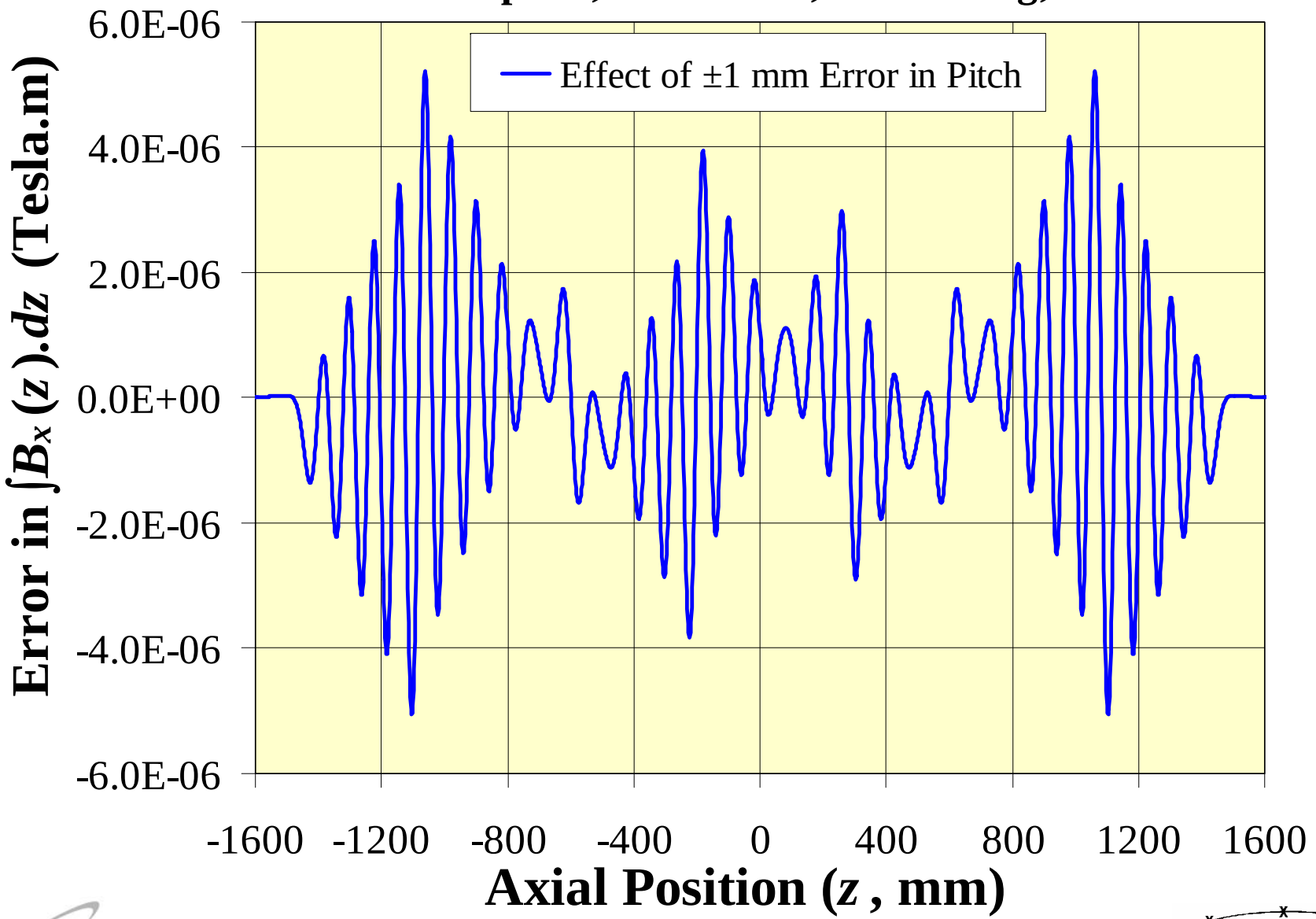

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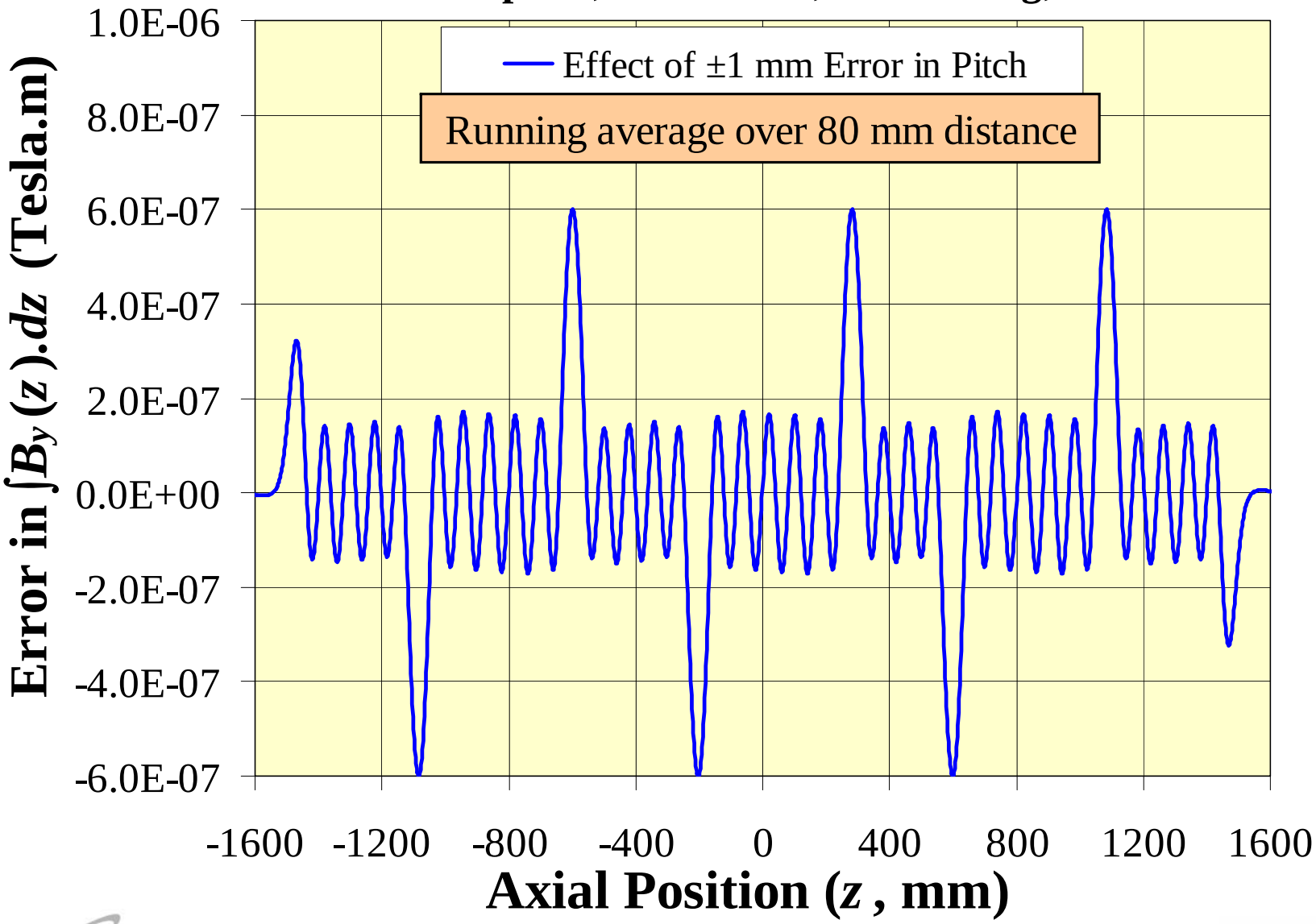

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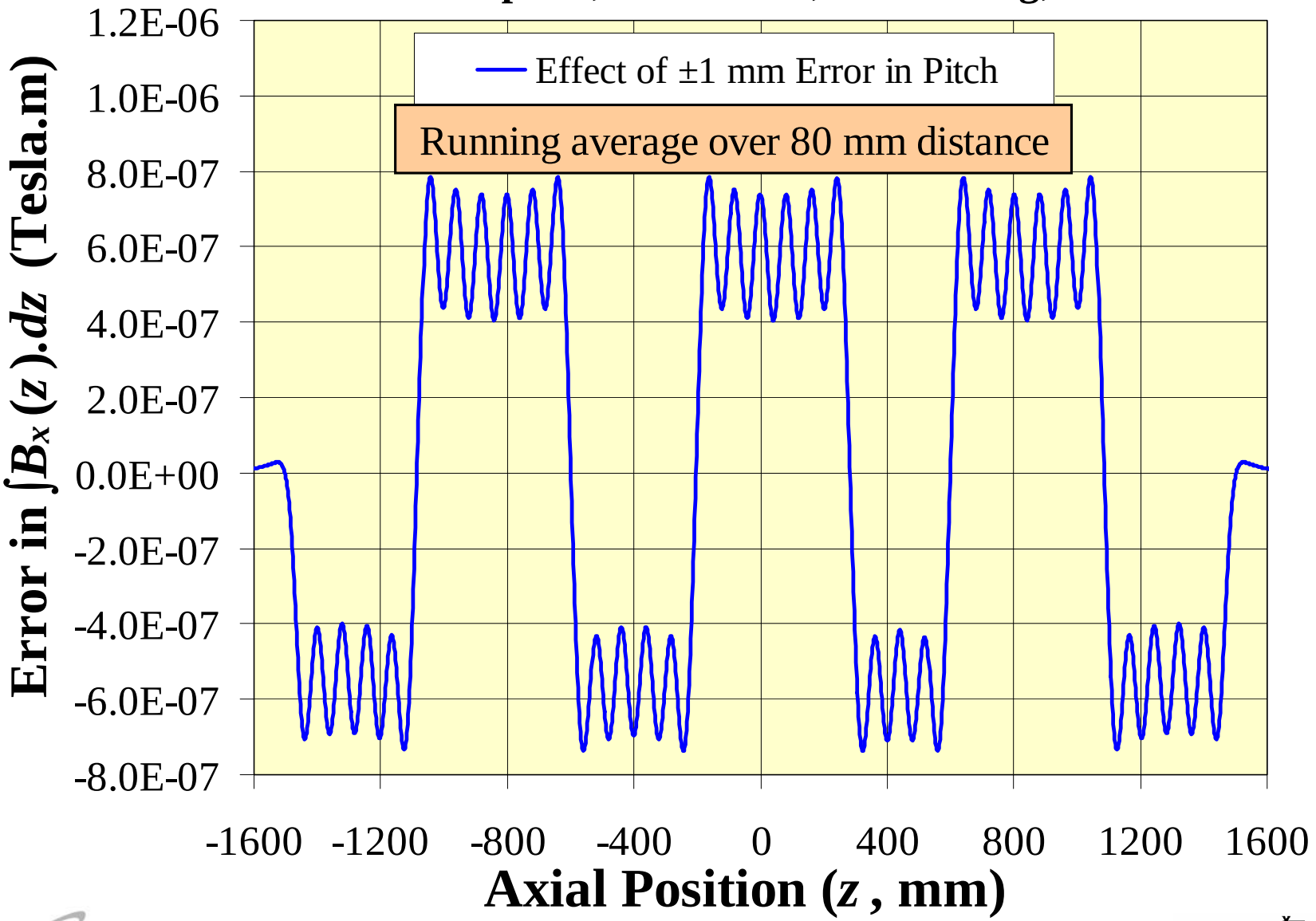
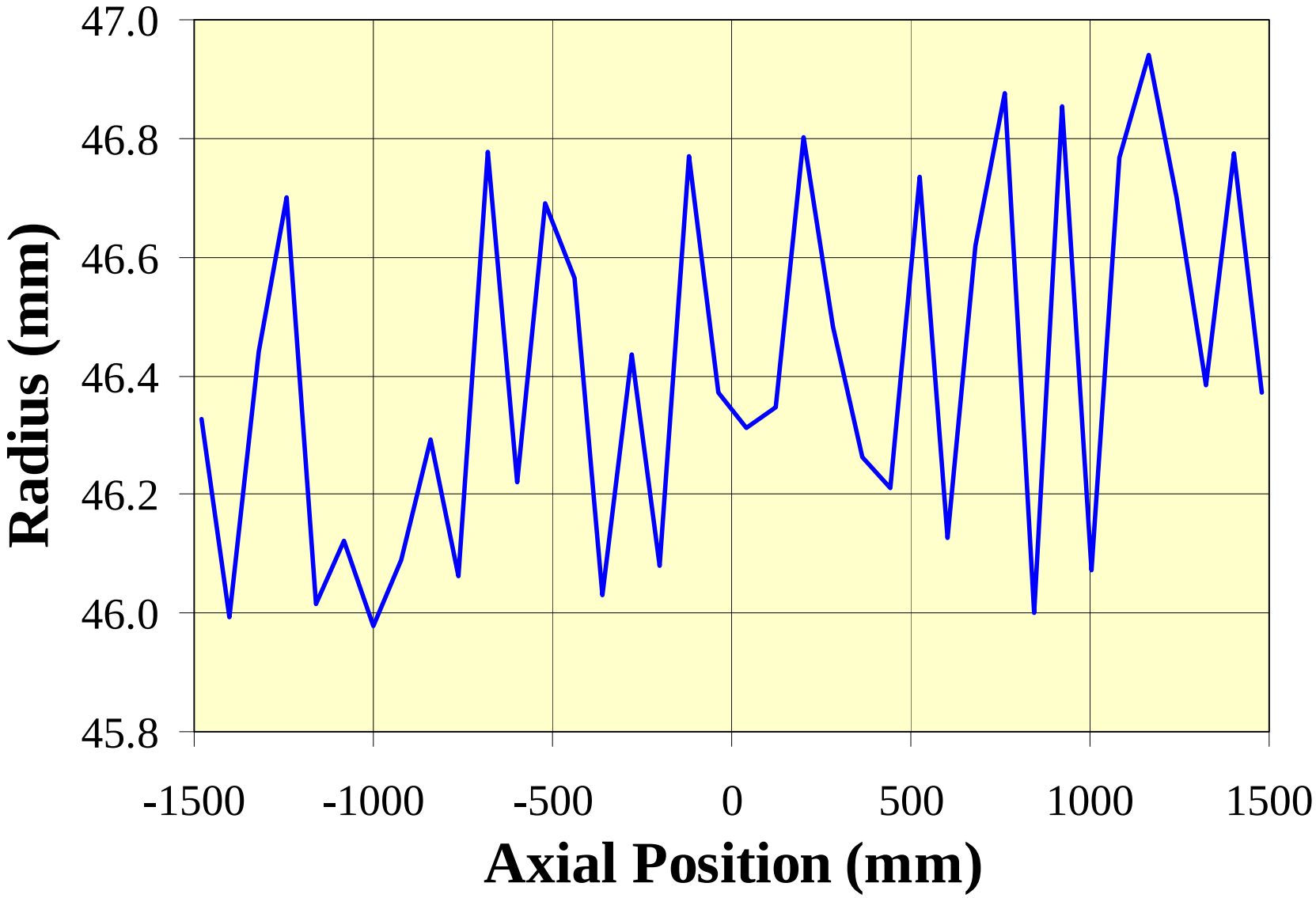


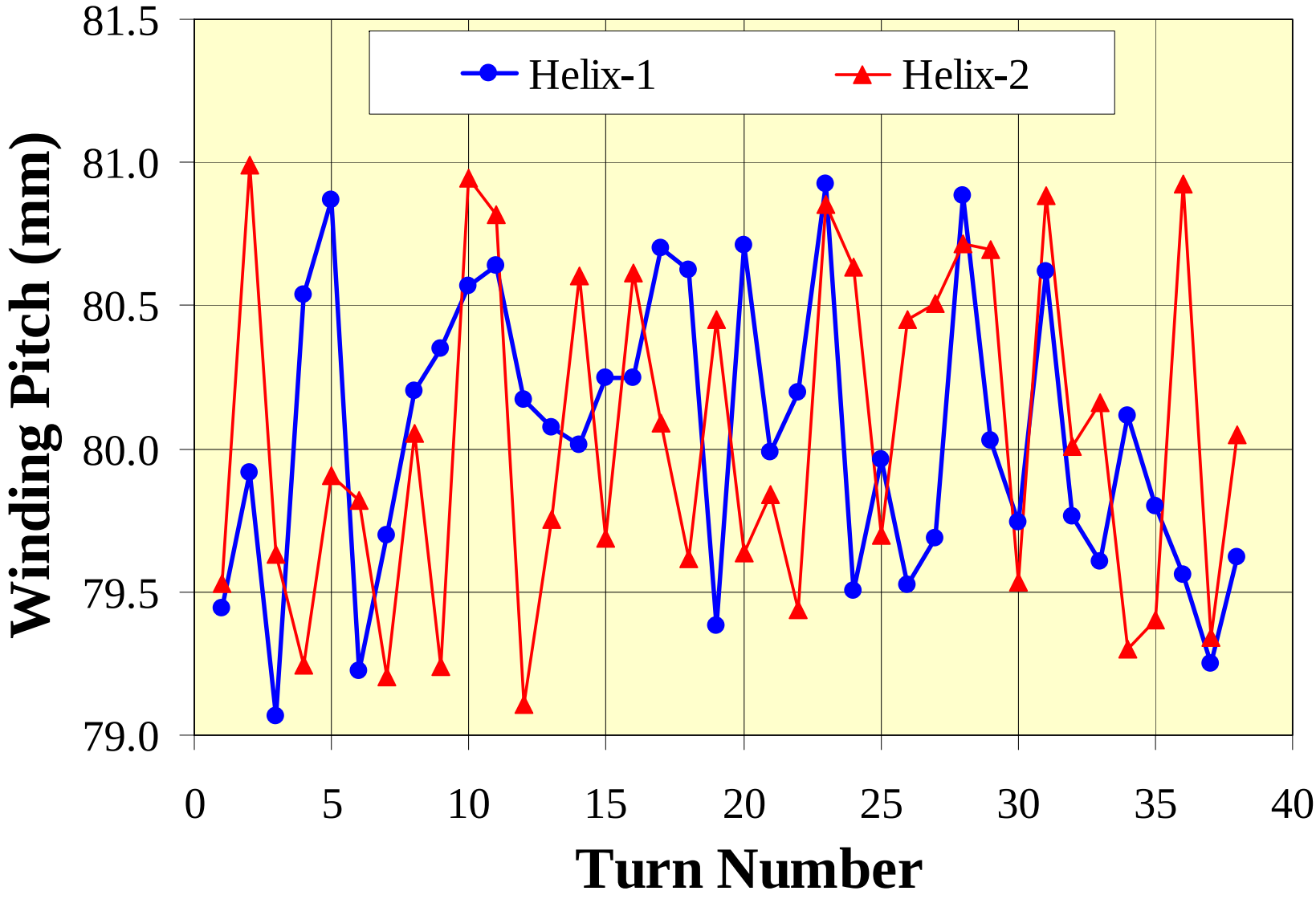
Modeling Random Construction Errors

- In practice, the radius and pitch would change by small, random amounts with each turn.
- Model broken into 1-turn segments.
- Each turn has a starting radius, an end radius, and a pitch, all assigned random values around nominal.
- The end radius of one turn is starting radius of next.
- The radii for the two helices have the same axial profile, but the pitch variations are different.
- Fields are computed on-axis, as well as on a tilted axis. (Only tilted axis results are presented here.)

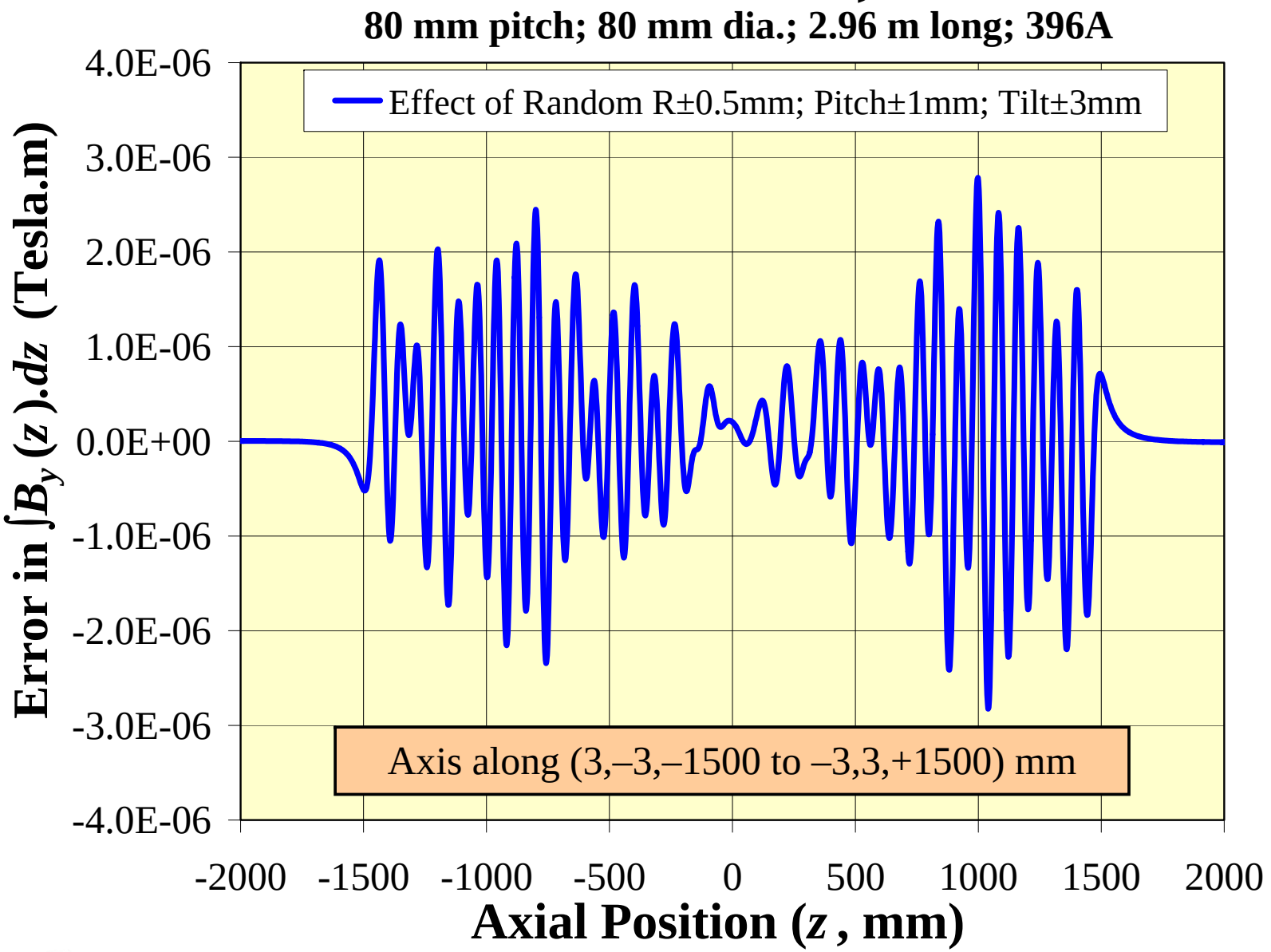
Random Radius Variations Used in Model



Random Pitch Variations Used in Model



Random Radius & Pitch; Tilted Axis



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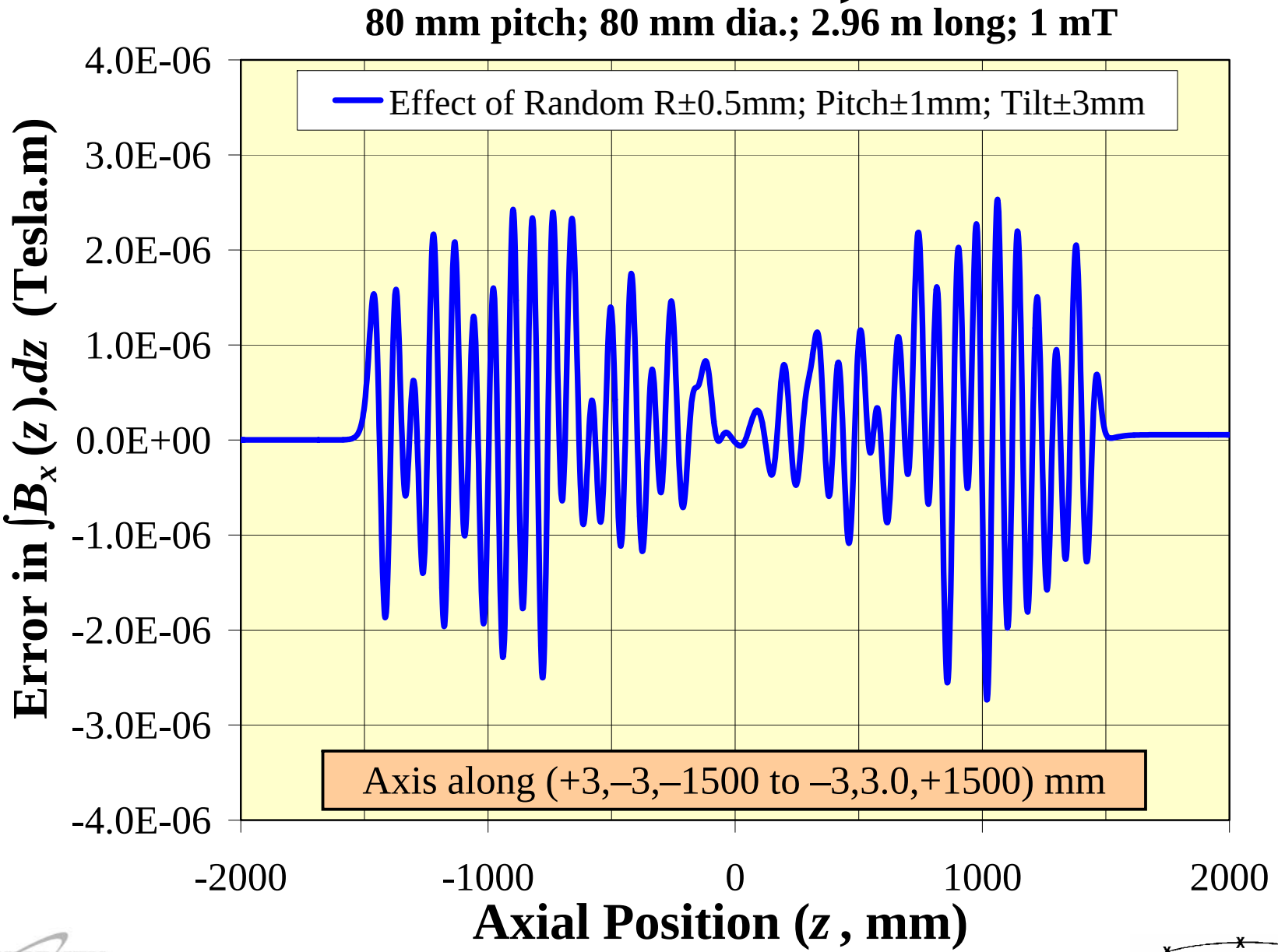

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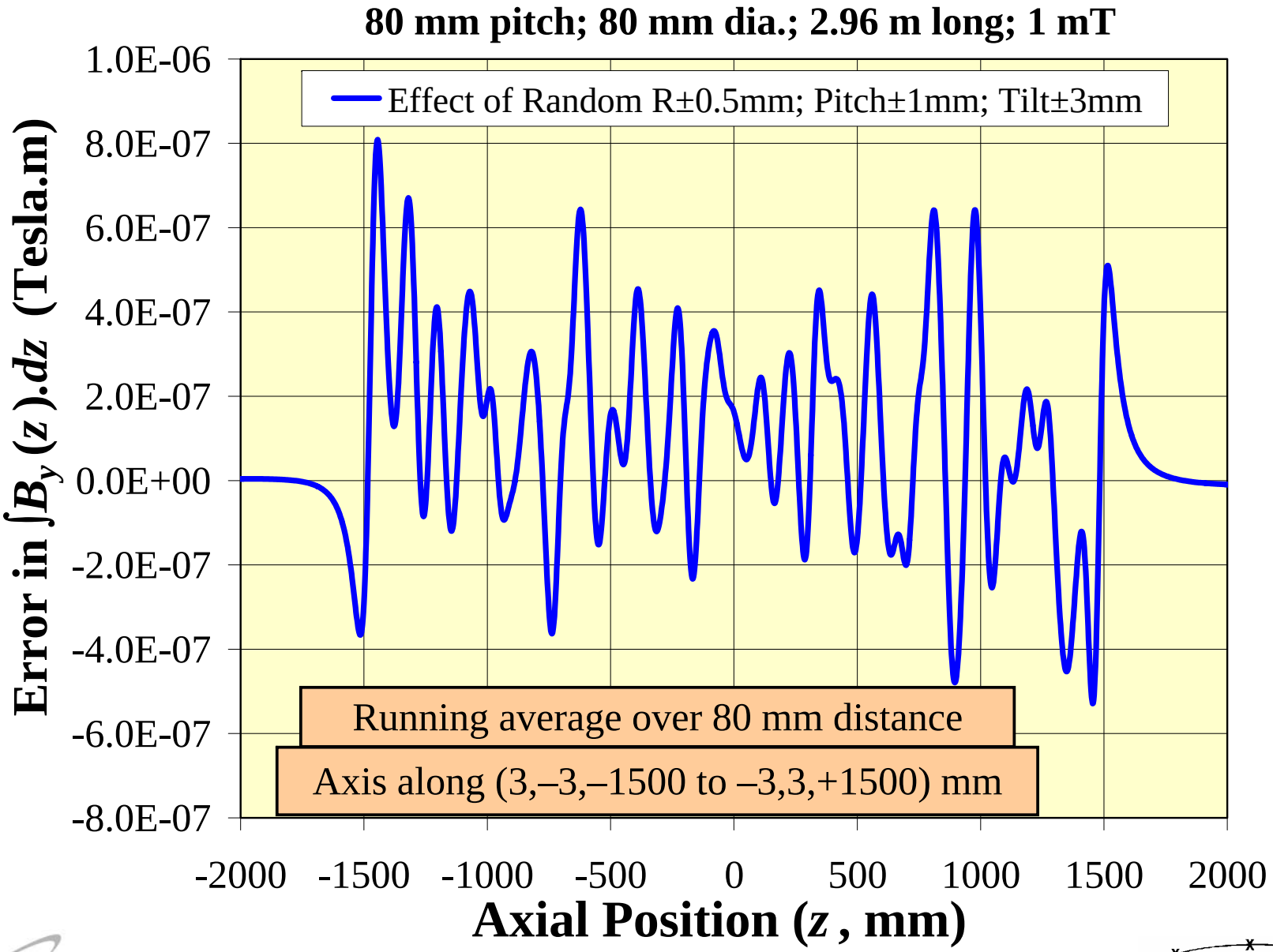

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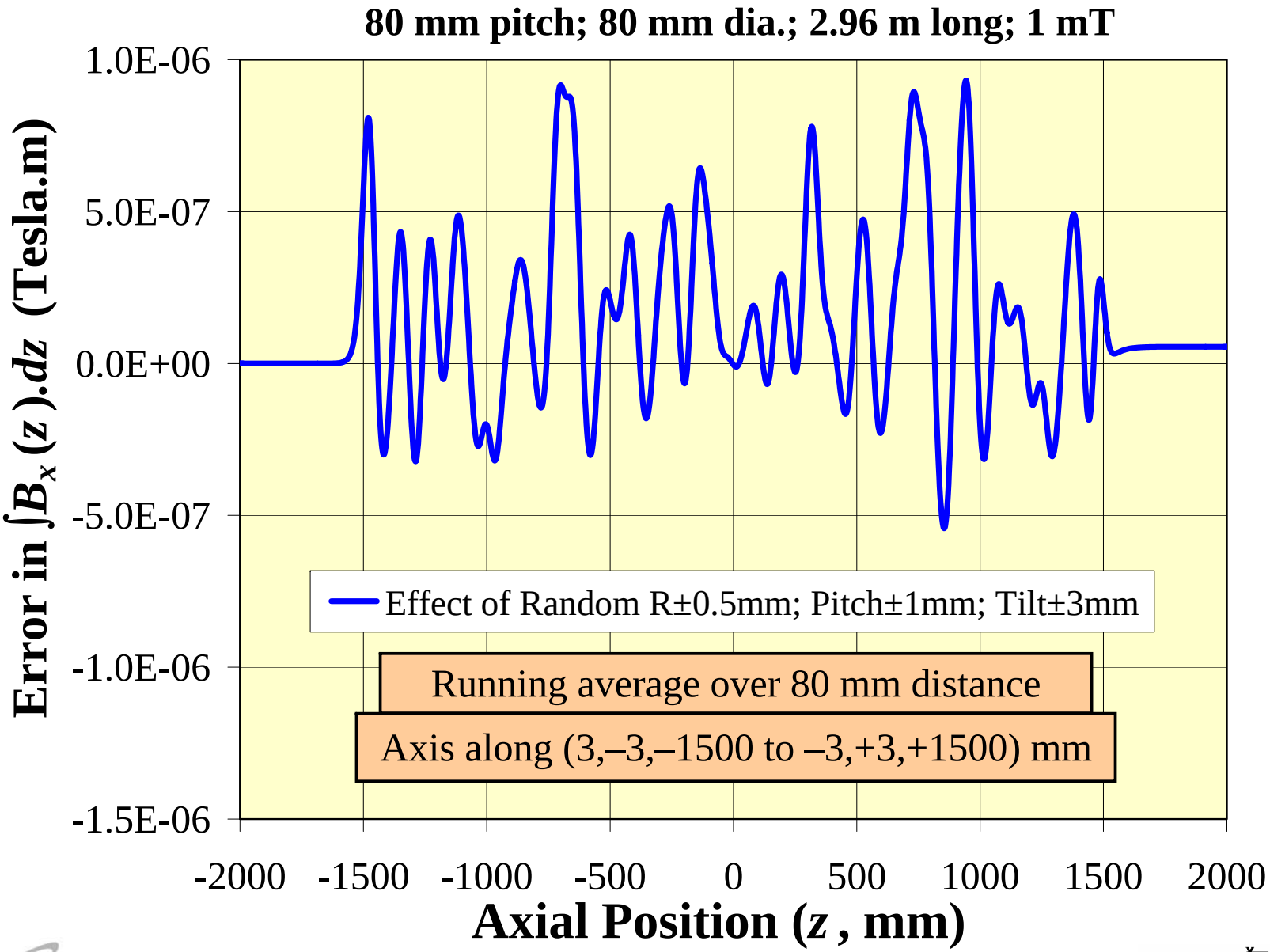

Summary

- A variety of construction and alignment errors have been studied for the undulator coil design.
- The magnitudes of errors considered were generally larger than what may be achieved with reasonable construction and installation effort.
- Even with the large errors, the effect on the field profile, as well as the field integral, is small for almost all types of construction errors.
- Most sensitive parameter seems to be the pitch.
- Calculations with random errors in radius and pitch for each turn also do not show any large deviations.