MIND Field Calculations

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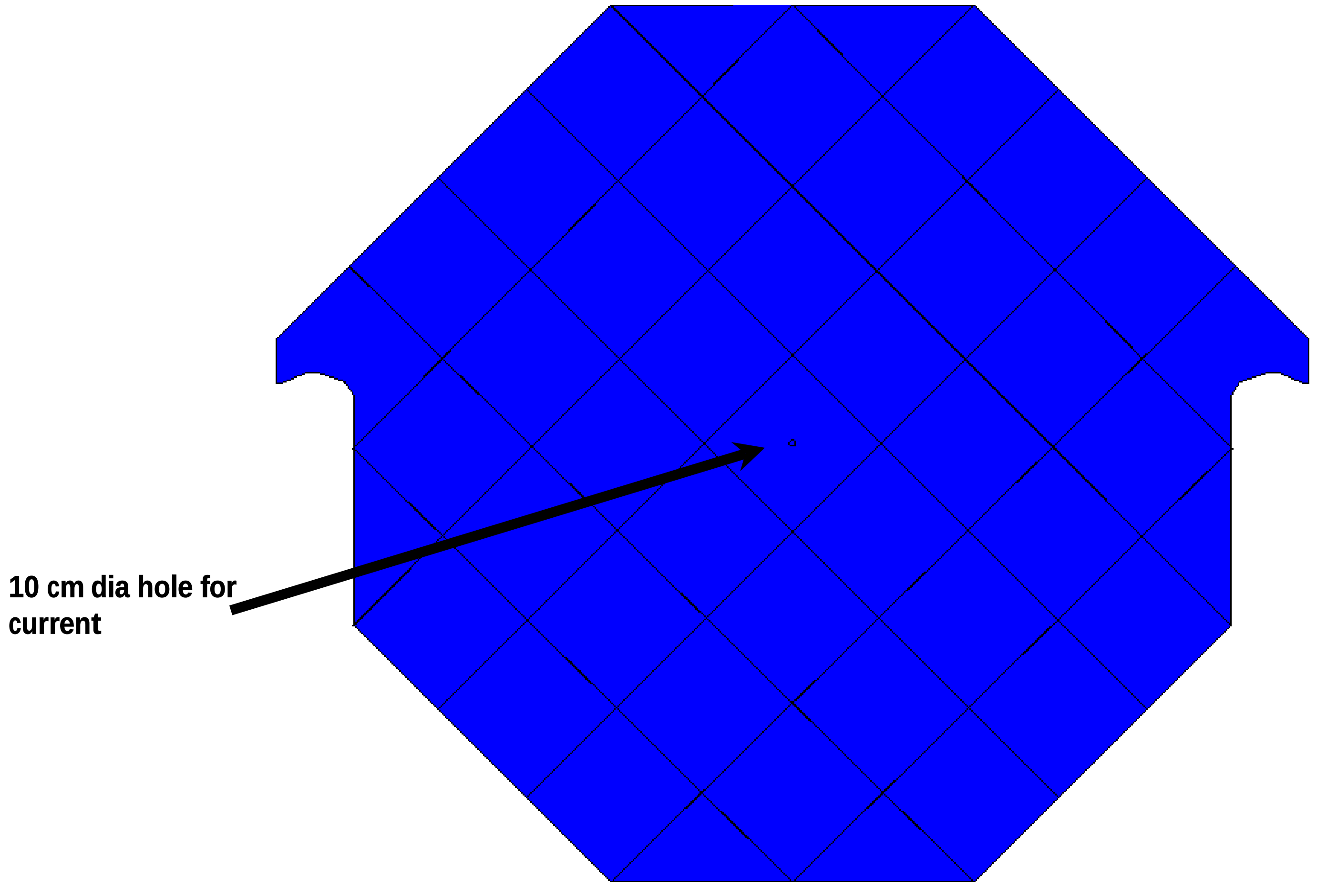
Overview of MIND Toroids

- The MIND toroids are octagonal planes with a 14 meter span across the flats
- There are two layers of 1.5 cm thick iron per plane
- Layers are plug-welded to each other
- Each layer consists of seven 2-meter wide plates
- Orientation of seams (slots) is rotated 90 degrees between layers
- Assembled plane is supported by ears
- Magnetization is provided by 100 kA current in 10 cm diameter central hole

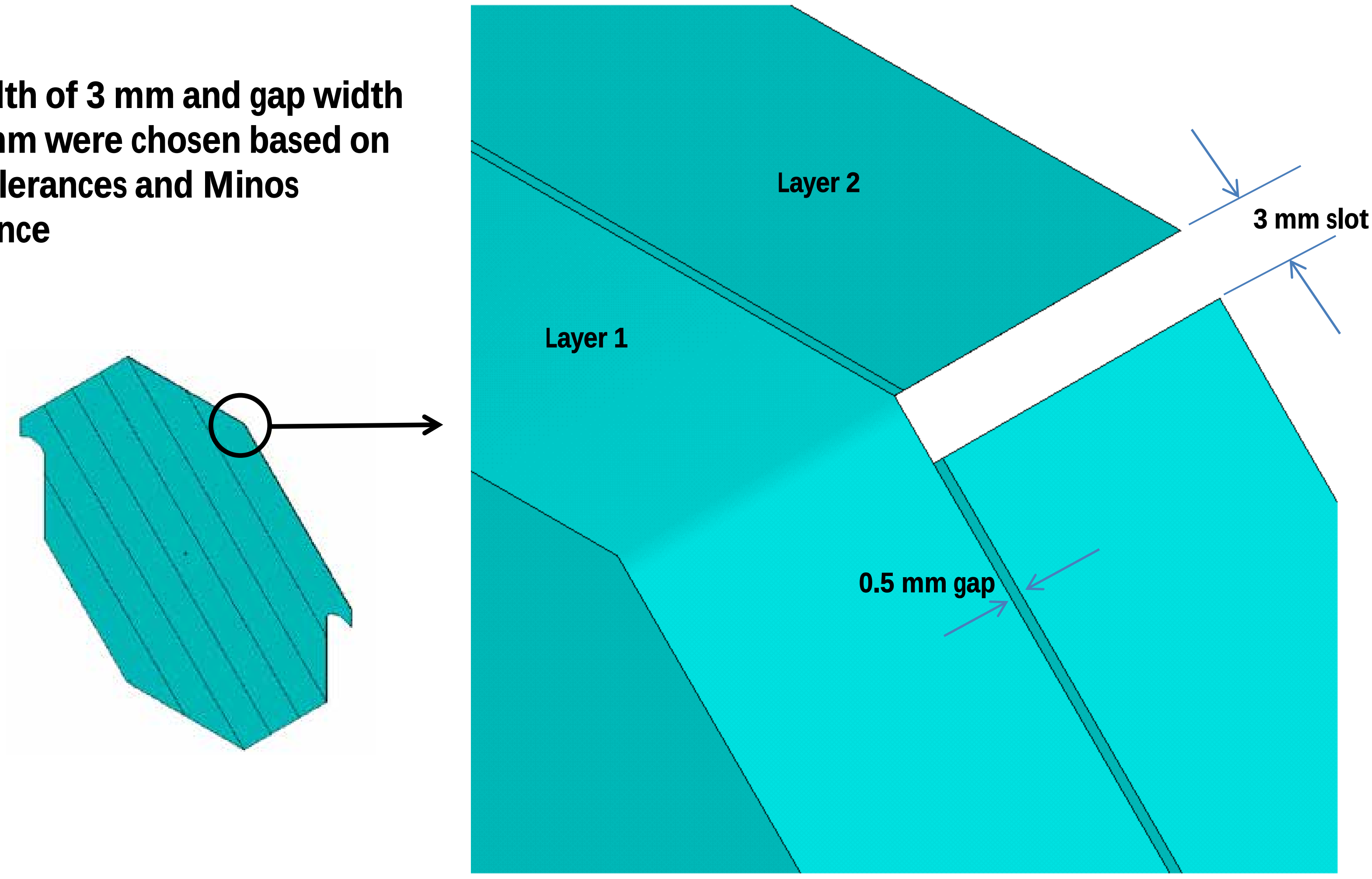
Plate Pattern – Slots in both layers are shown



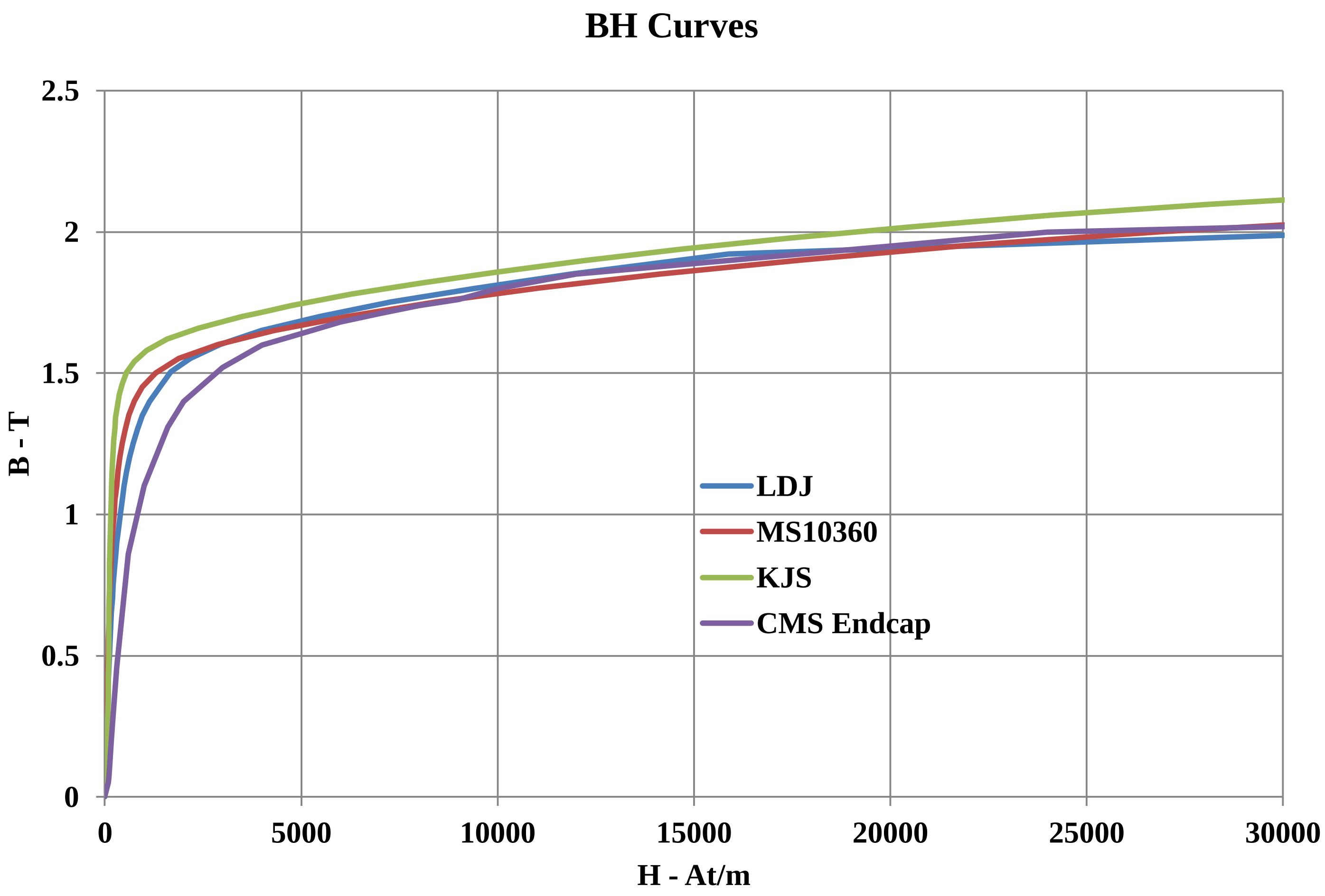
Note: All 3-d plots shown in this presentation have the slots on the visible face running from the upper left to the lower right

Detail of slots and gaps in MIND plane

Slot width of 3 mm and gap width of 0.5 mm were chosen based on plate tolerances and Minos experience



- The LDJ, MS10360, and KJS curves were measured for the Minos experiment.
- The CMS Endcap curve was measured by PSL-Wisc for the CMS endcap iron
- The CMS Endcap curve was used in the analyses presented here, as it is the most “conservative” of the curves.



2-d Model

1. **Element is 8 node quadrilateral, ANSYS Plane53 – superb element**
2. **Formulation is magnetic vector potential**
3. **Model is incapable of generating a z-component of field**
4. **Model is assumed to represent a region far from ends of magnet**
5. ***Current is applied as a current density to a circular region of elements at the model center 10 cm in diameter***
6. **Element size in the iron plane is 2.5 cm**
7. **Total degrees of freedom is 1.1 million**

3-d Model

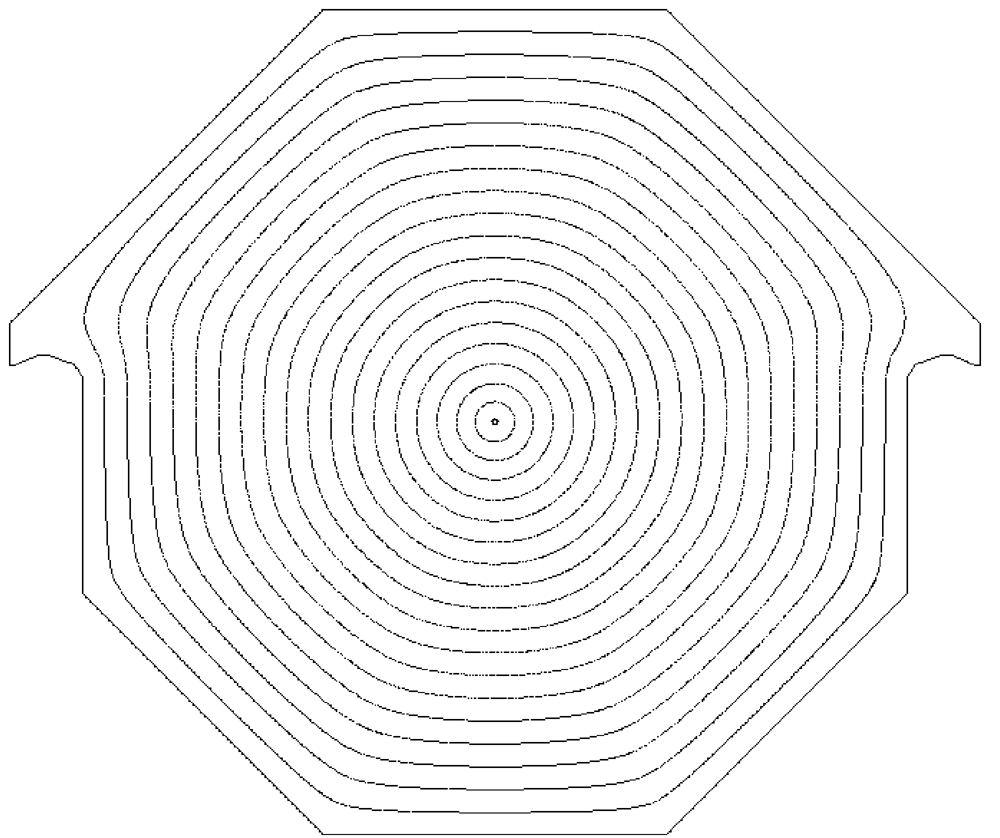
1. **Element is 8 node brick, ANSYS solid96**
2. **Formulation is magnetic scalar potential**
3. **Model will generate a z-component of field if necessary**
4. **Model is assumed to represent region far from ends of magnet**
5. ***Current is applied as a total NI in a Biot-Savart primitive with a square (0.0707 m x 0.0707 m) cross section***
6. **Element size in the iron plane is 2.5 cm**
7. **Total degrees of freedom is 4.7 million – very fine for 3-d, but we could go finer**

Approach to Verification of the Analysis

- The 2-d and 3-d ANSYS magnetic models are compared for the case of homogeneous iron. With homogeneous iron, the two models are simulating precisely the same toroid.
- It will be shown that the two models – which differ in formulation, dimensionality, and element order – produce very similar results
- This exercise is necessary because the true 3-d configuration with slots and gaps cannot be simulated satisfactorily in 2-d, and therefore confidence in the 3-d model is imperative.

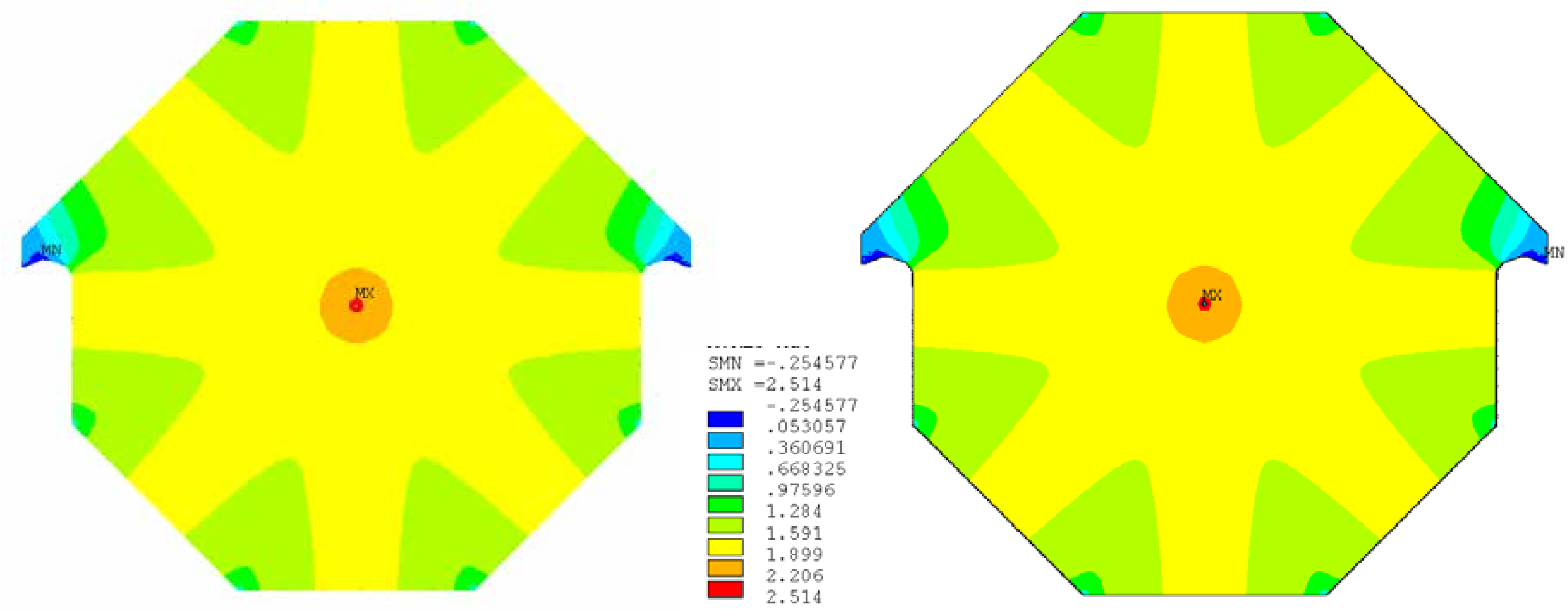
Note: Neither the 2-d nor 3-d model includes the current return bus. When the location of this bus is specified, it can be easily added to the models

Flux Lines from 2-d Analysis – homogeneous iron



Mind 2-d for field mapping

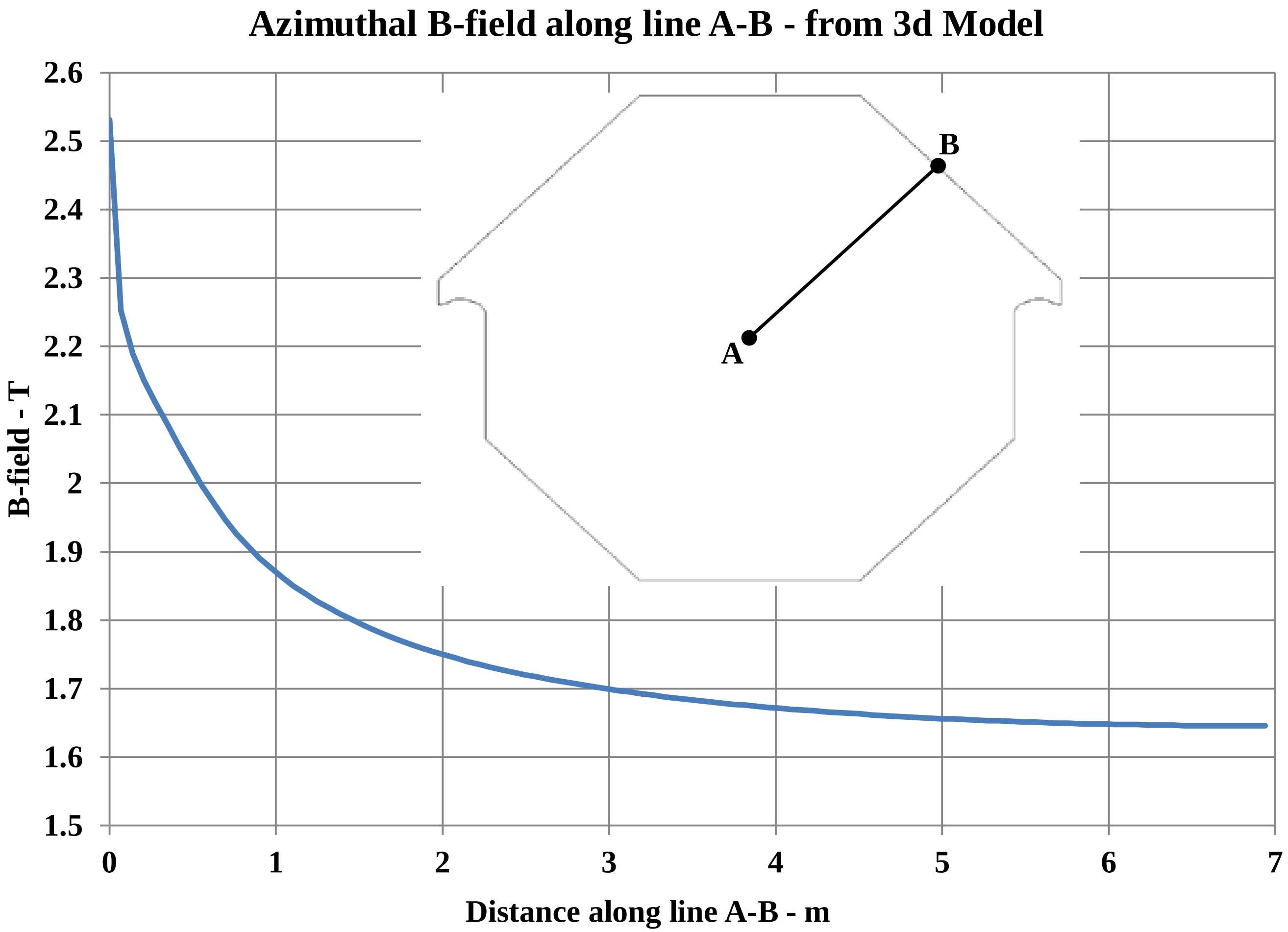
ANSYS results for azimuthal B-field – homogeneous iron
Comparison of 2-d and 3-d results



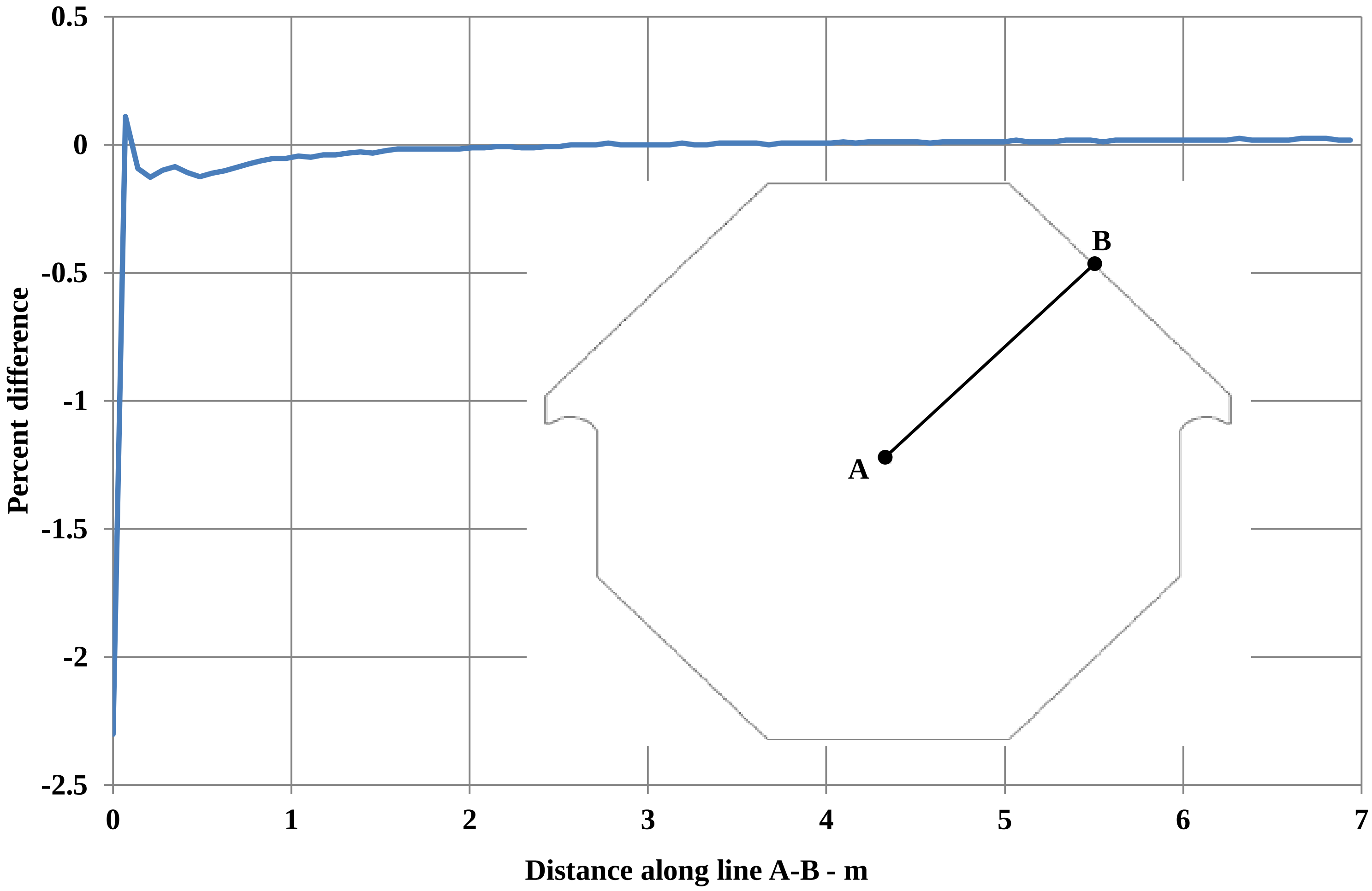
2-d model

3-d model

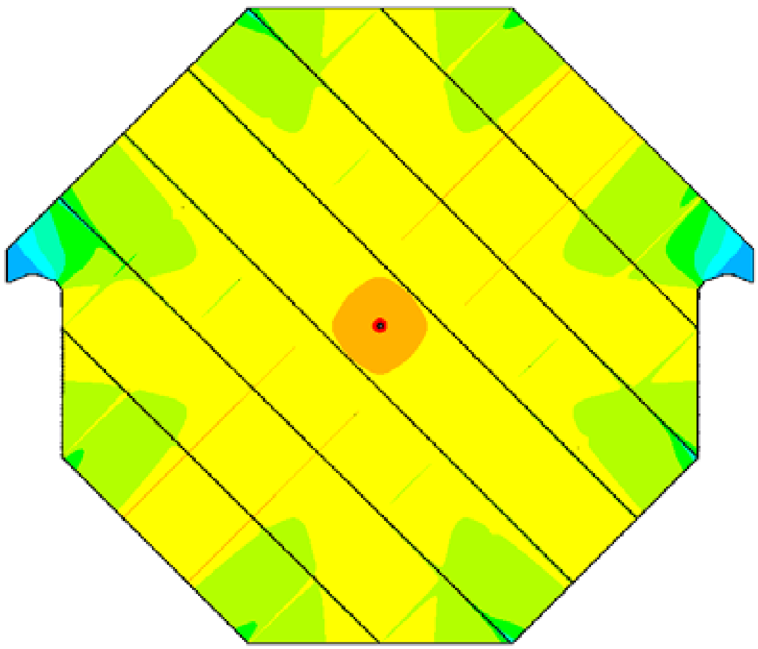
Note: Results for 2d and 3d model with homogeneous iron are essentially identical on scale of plot

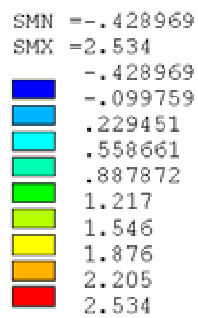


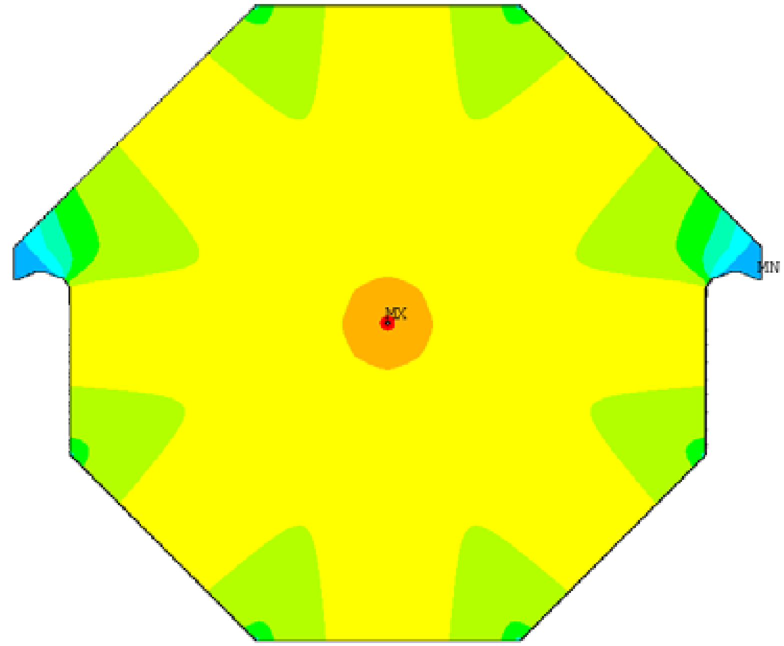
2d and 3d Azimuthal B-field Comparison – Homogeneous Iron



Azimuthal B-field from 3-d Model with slots and gaps



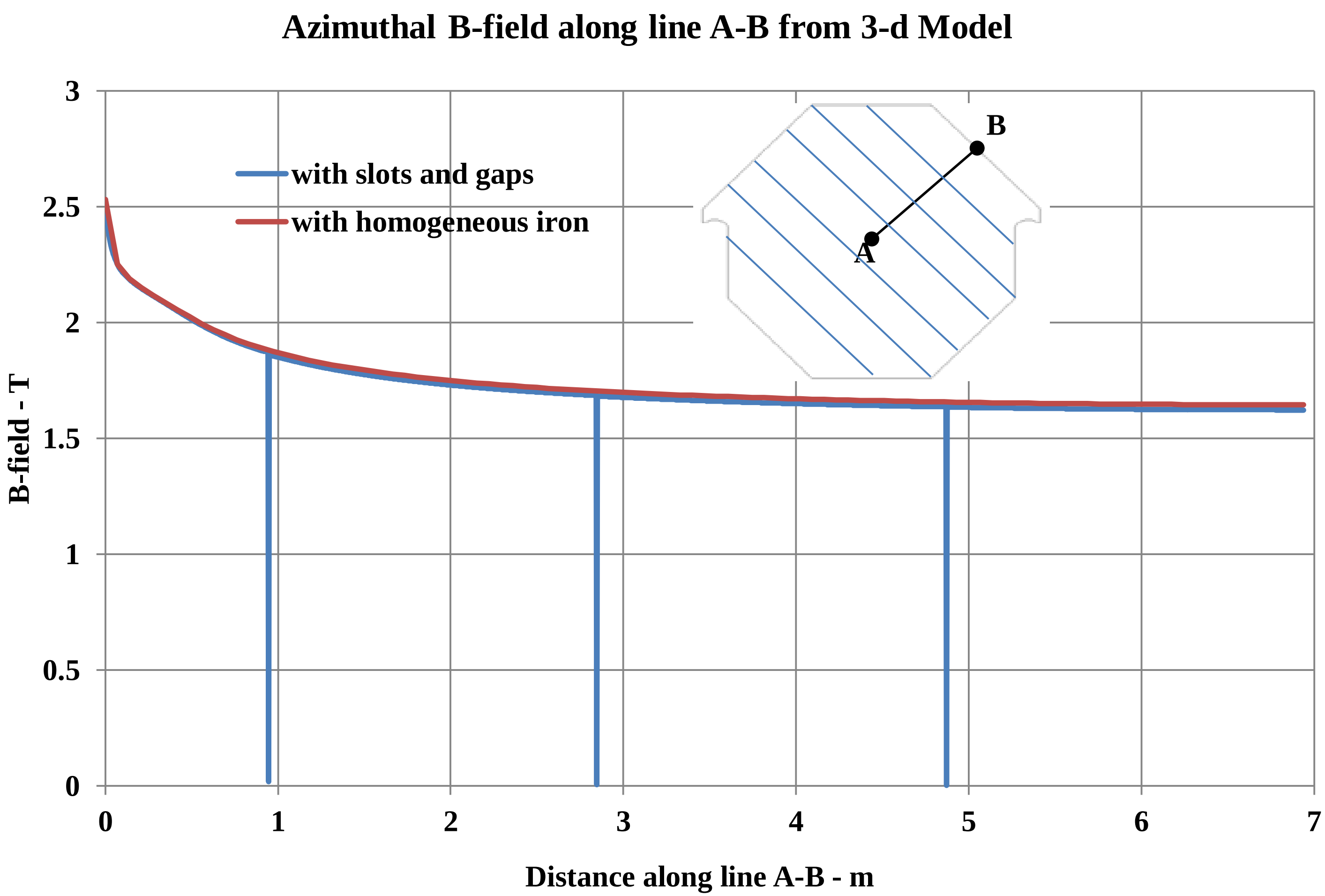




With slots and gaps

With homogeneous iron

Note: path is in the middle of layer 1, i.e., 7.5 mm below the surface of layer 1



Through-the-Thickness Variation of Field in a Layer

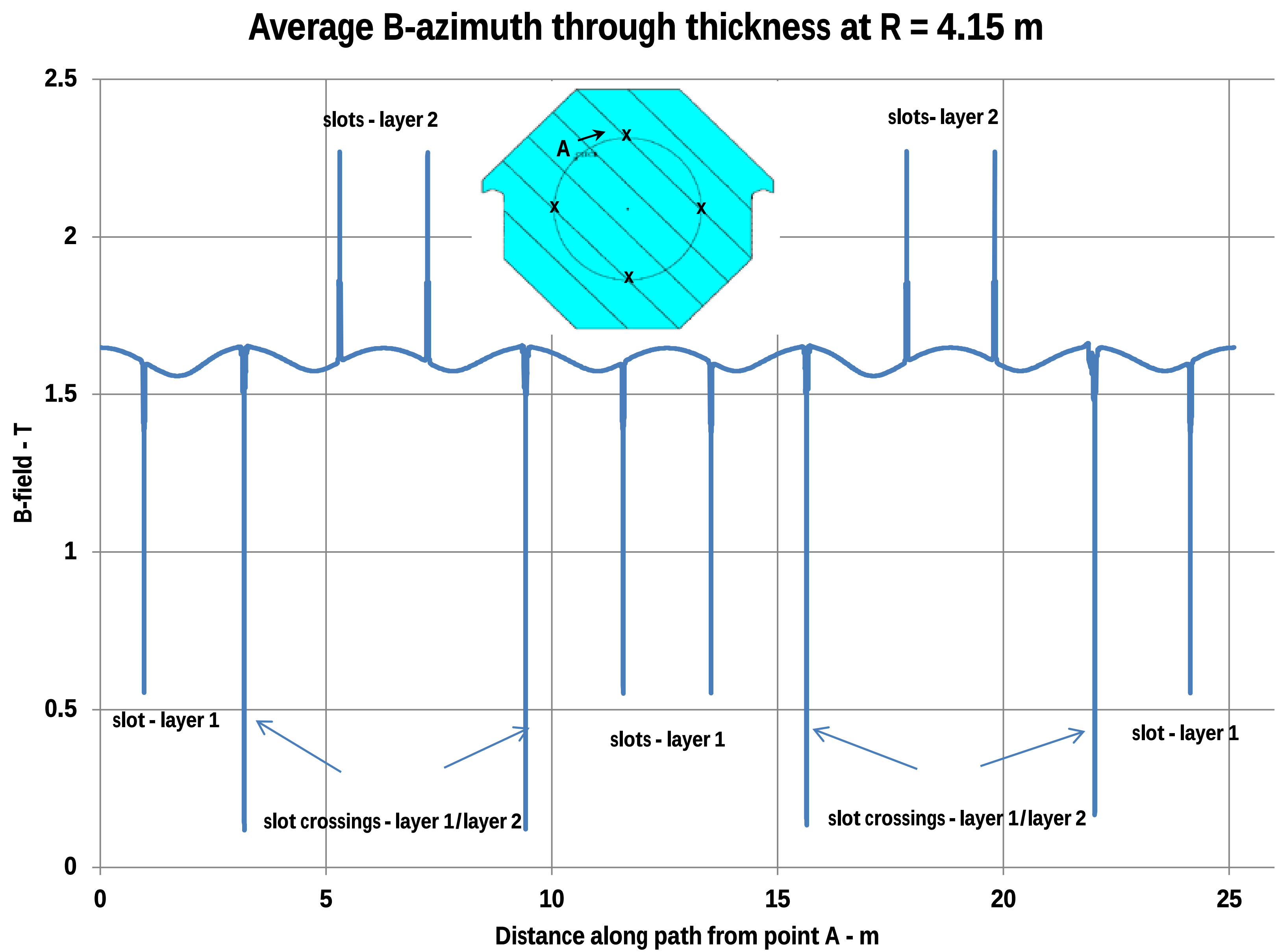
- To examine the through-the-thickness variation of field in a layer, five circular paths with radius 4.15 m were created at five different z-depths in layer 1. Depths were 0, 0.375 cm, 0.75 cm, 1.125 cm, and 1.5 cm.

- The azimuthal b-field was calculated around each path at 25000 points (about 1 mm spacing to ensure hitting slots)

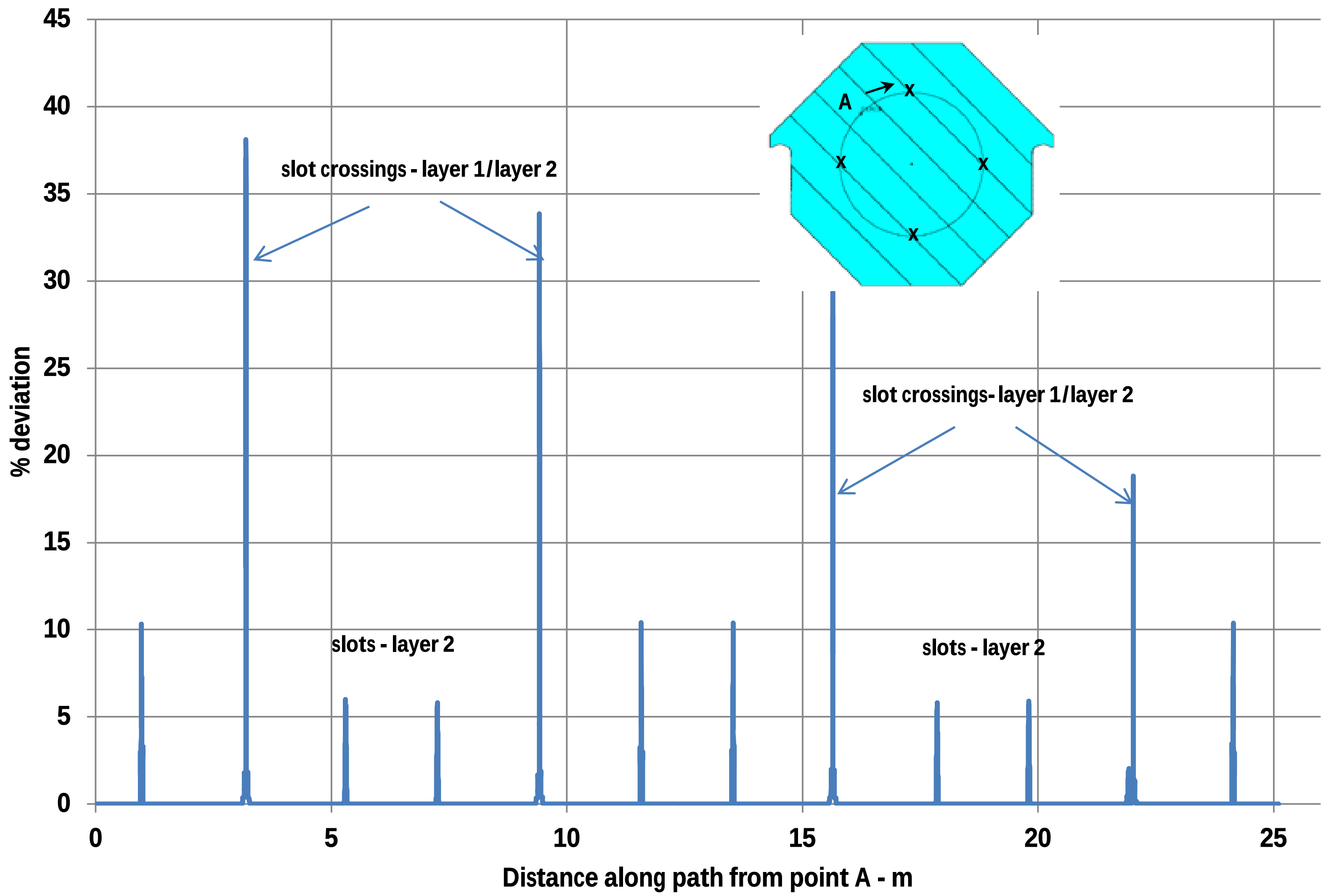
- The azimuthal b-fields at the five points through the thickness were averaged and plotted

- The maximum deviation of the five through-the-thickness values from the average value was plotted

Note: Radius of 4.15 m was chosen to have the paths pass directly through four regions where the layer 1 and layer 2 slots cross. In these regions, there is a 3x3 mm hole through both layers of iron


Average B-azimuth through thickness at R = 4.15 m
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Distance along path from point A - m
B-field - T
slots - layer 2
slots- layer 2
A
x
x
x
x
slot - layer 1
slots - layer 1
slot - layer 1
slot crossings - layer 1/layer 2
slot crossings - layer 1/layer 2

Maximum deviation from average field through thickness



Current Status

- A 3-d field map on a 5 cm grid has been generated for the mid-layer z-positions of layer 1 and layer 2 for preliminary evaluation by the collaboration
- The field map can be produced in any arbitrary z-plane through a given plane of iron.
- Smaller grid sizes are possible; files grow very large
- Slot and gap sizes can be varied in future work; Minos assumed a variation of slot size based on observation of actual assemblies.