Evaluation of applicability of 2D iron core model for two-limb configuration of GOLEM tokamak

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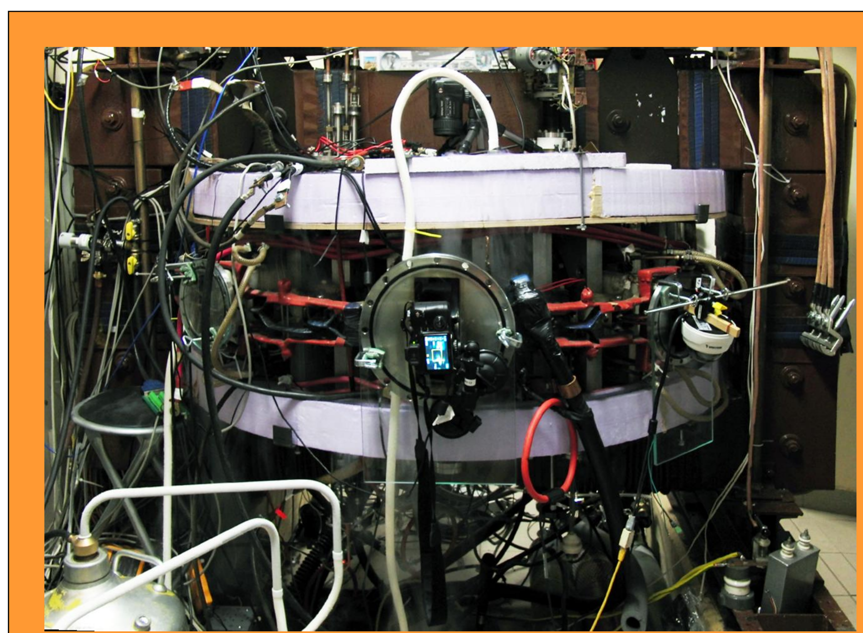
Introduction

- In tokamaks with iron core (e.g. JET), distribution of magnetic field is affected by iron core presence.
- On tokamak GOLEM, $\mathbf{B_R}$ of 2-3 times stronger magnitudes were measured than those calculated from air core approach [1].
- RMP field coils on JET tokamak are in vicinity of iron core and due to toroidal non-axisymmetry, full 3D approach is necessary to calculate their field.
- Development of 2D model – first step to 3D code.

Tokamak GOLEM



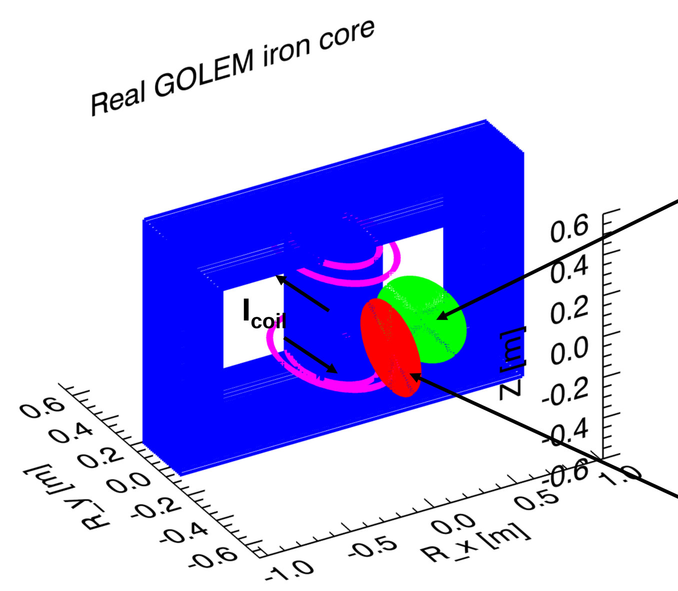
Small tokamak of Czech Technical Univ. used for fusion education on national and international level. Also used to test new plasma diagnostics and for high temperature supraconductor (HTS) studies. Until end of 2007 being operated on IPP AV CR as tokamak CASTOR.

Advantages of using GOLEM for 3D code benchmarking:
- Strong toroidal non-axisymmetry of its iron core.
- Flexible device with easily accessible chamber.
- Newly installed HTS [2] will enable steady-state magnetic field measurements to be used as well.

R = 0.4 m
a = 8.5 cm

B_T < 0.5 T
I_P < 4 kA

Conditions of measurement:
- "Vacuum" field measurements in open chamber.
- Capacitor battery discharged into poloidal field coils close to central column (purple). Current direction implies generation of magnetic field outward from central column of tokamak.
- Local $\mathbf{B_R}$ field measured by a Hall probe.
- Poloidal $\mathbf{B_R}$ distribution measured inside of tokamak chamber on planes of different toroidal angles.
- Red – pi/2, green – pi/4.



Axisymmetric core model

Presence of external magnetic fields (e.g. from plasma or poloidal field windings) causes induction of eddy currents in ferromagnetic core. According to [3,4], effects of these currents can be represented by iron-air boundary surface currents σ :

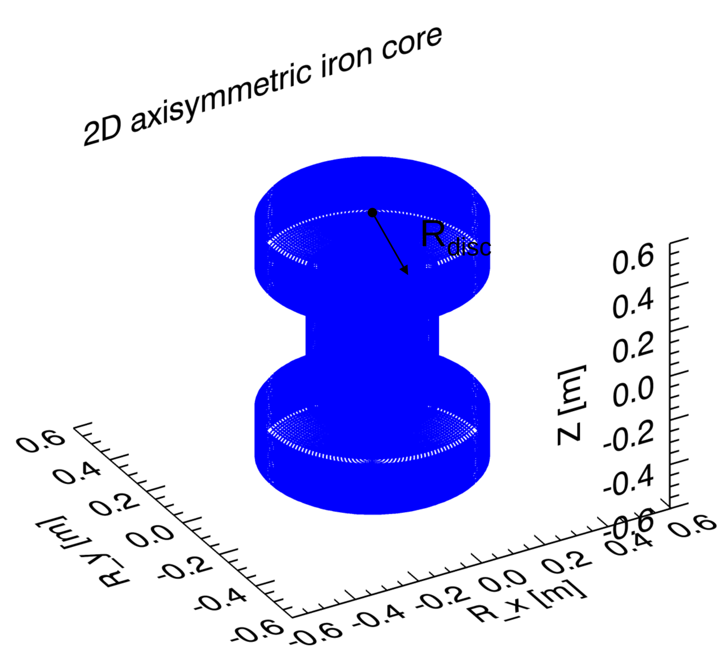
$$\sigma(\mathbf{r}) - \frac{\lambda}{2\pi}\int_S \left(\sigma(\mathbf{r}') \times \frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3}\right)\times \mathbf{n}(\mathbf{r})\,\mathrm{d}S' = \frac{\lambda}{2\pi}\int_V \left(\mathbf{j}(\mathbf{r}') \times \frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3}\right)\times \mathbf{n}(\mathbf{r})\,\mathrm{d}V'$$

n – normale to boundary surface
j – external current densities

$$\lambda(|\mathbf{B}|) = \frac{\mu_r(|\mathbf{B}|)-1}{\mu_r(|\mathbf{B}|)+1}$$

Discretization into finite no. of filaments: Set of 3N non-linear equations in 3D

Non-linearity is due to λ term



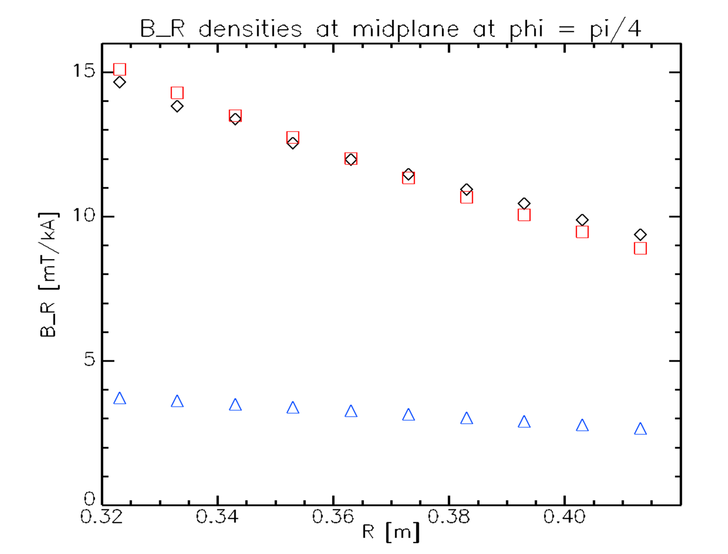
2D linear approximation:

- Investigation of axisymmetric approach applicability – toroidal component of $\boldsymbol{\sigma}$.
- Constant μ_r due to small magnitude of $\mathbf{B_R}$ generated by poloidal field coils.

Only set of N linear equations is necessary!

Question: Is it sufficient to approximate 3D geometry of real core by change in radii of upper and lower discs?

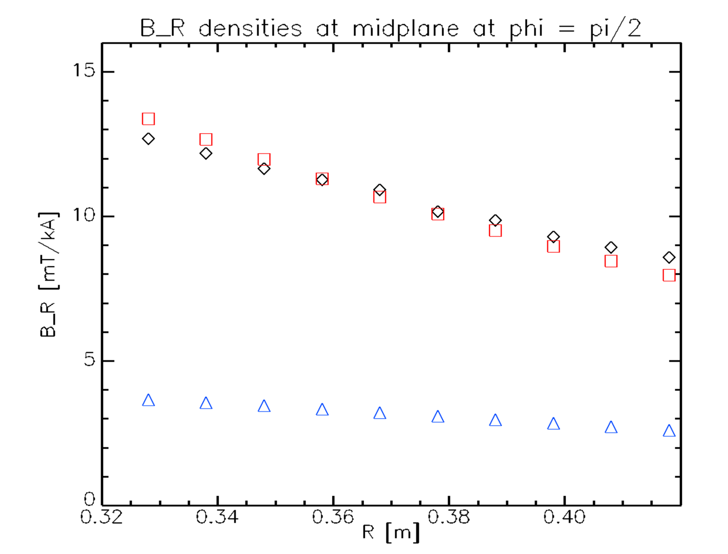
Results: Measurements vs. Model



◇ Measured values
△ Air core model
□ 2D iron core model

Model with R_{disc} = 1.75 R_{cen}

R_{cen} represents radius of core column

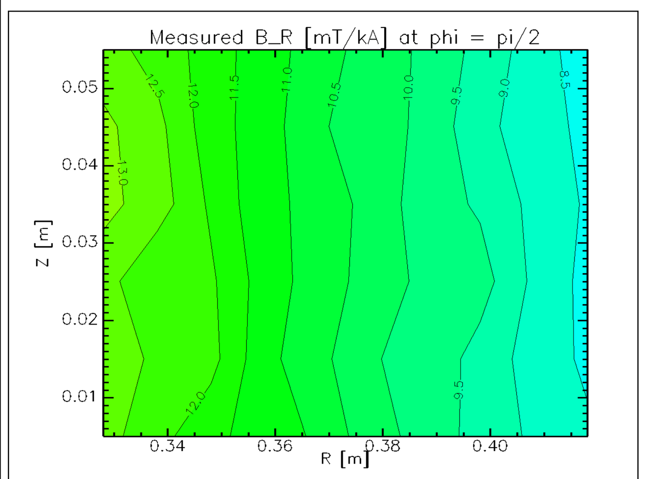


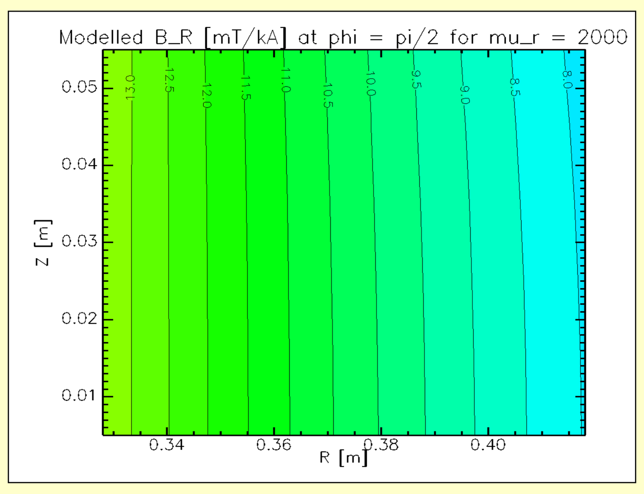
◇ Measured values
△ Air core model
□ 2D iron core model

Model with R_{disc} = 1.50 R_{cen}

- Field is amplified by factor ~ 3 because of iron core!
- Results by 2D axisymmetric model with constant μ_r have good quantitative correspondence to measurements.

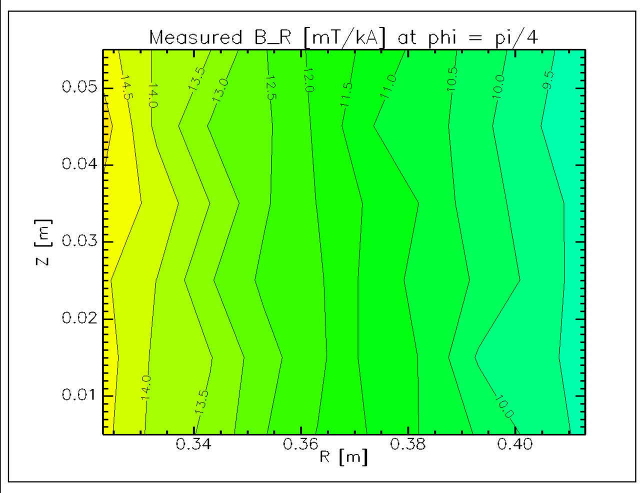
However:
- Radii of upper and of lower discs need to vary with toroidal angle of modeled plane location.
- Predictive capabilities of model are limited by necessity of apriori measurements.
- Primary field sources were located close to symmetric part of iron. Results might vary, if coils on low-field side were used – will be investigated in future works.
- Constant μ_r approach is not entirely correct. μ_r(B) for GOLEM needs to be determined as soon as possible.

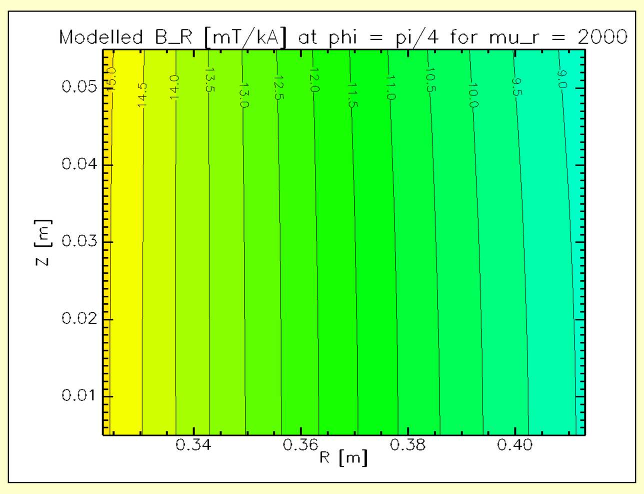


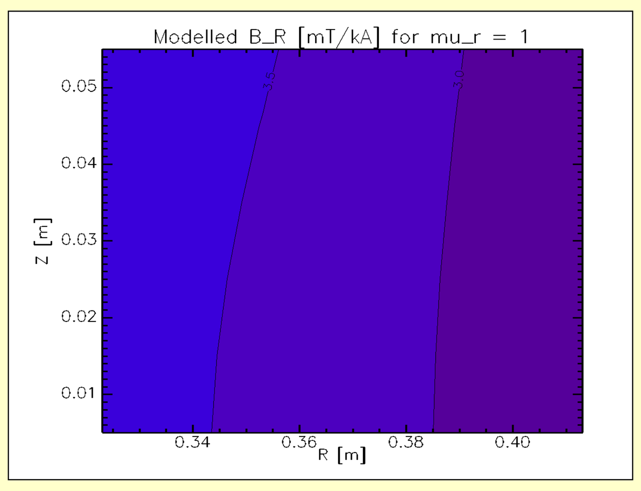


Iron core model provided good quantitative and qualitative correspondence to measurements.

Results by air core approach significantly differ from measurements.







Summary

- Linearized, axisymmetric form of the future 3D code explained calculation-mesurement discrepancy from [1].
- Good qualitative and quantitative correspondence with measurements was obtained by use of 2D model.
- Therefore, this approach has good applicability for poloidal field coils placed close to central iron core column.
- For different toroidal angles, dimensions of axisymmetric equivalent of core need to be varied.
- Future work will investigate fields further from the central column and approach the non-linearity and 3D generalization issues.

References

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[4] O. V. Tozoni, et al., Calculation of three-dimensional electromagnetic fields, Tekhnika, Kiev, 1974