UW-Madison table-top stellarator experiment - parameters and design

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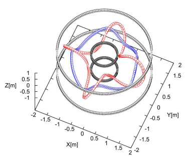
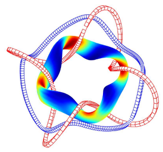
Motivation

- Design a table-top stellarator feasible for lab courses and Helicon wave experiments
- Based on coil equations from Yamaguchi [1]

$$R(\phi) = R_0\epsilon_r \cos(N\phi + \alpha_r \sin(N\phi)) + R_0$$
$$Z(\phi) = R_0\epsilon_z \sin(N\phi + \alpha_z \sin(N\phi))$$

  - R_0 is the major radius, $\epsilon_{r,z}$ are the ratio of radial and vertical minor radii to major radius, N is the periodicity, $\alpha_{r,z}$ control the radial and vertical pitch

- The original design uses 2 4-period helical coils and 4 vertical field coils
- However, coils are very close to the plasma in the high-field regions → very difficult to build

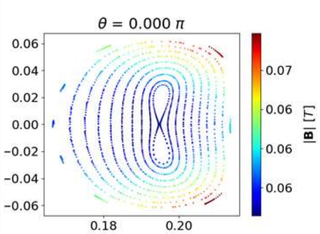
→ Identify an alternative design that is easier to realize

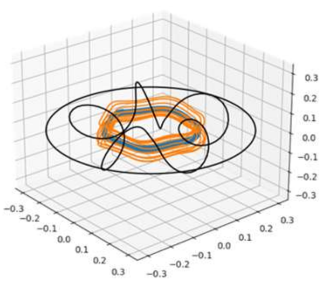
New coil geometry

- Identified using a new field line following code written in python
  - Calculate the magnetic field of arbitrary coils using the Biot-Savart law
  - Follow field lines using the leapfrog method:

$$x_{n+1} = x_n + |\vec{B}(x_n + .5|\vec{B}(x_n)|)|$$

- One planar coil in combination with one helical coil provides good confinement
- 5 periods instead of 4 works without additional vertical field coils





Grid search to satisfy engineering constraints

Constraints

- A minimum of 2 cm is required between the coils and the vacuum vessel (cylindrical glass vessel)
- Placement of the planar coil outside of the helical coil
- Reasonable plasma volume

Parameter scan

- Coil system described by 6 free parameters: (R_0, R_1, ϵ_z, $\alpha_{r,z}$) and the ratio of currents in coils 1 and 2.
- Scan the parameter space using 15 different values for each parameter (11 M configurations)
- 682 configurations with closed flux surfaces identified

	R_0	R_1	ϵ_z	α_z	α_r	Current ratio
Minimum	.18	$f(R_{0,min})$	$f(R_{0,min})$	.1	.1	-2
Maximum	.25	$f(R_{0,max})$	.9	.8	.8	-7

VMEC Results

Inputs

- Fourier decomposition of last closed flux surface
- MGRID with radial, vertical and poloidal mesh size < .1mm
- Pressure (here vacuum approximation)

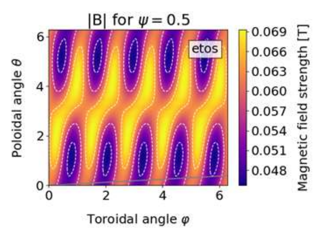
Output

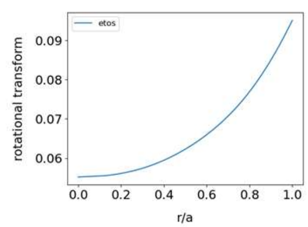
- $|B|$, rotational transform, normalized curvature and Fourier amplitude plots

318 successful VMEC output files obtained:

- Several configurations exhibit reasonable values of the rotational transform
- $|B|$ plot shows the magnetic field structure

Configuration 592



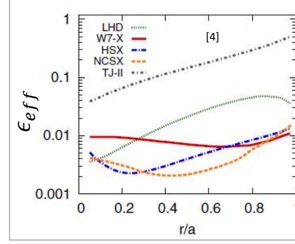


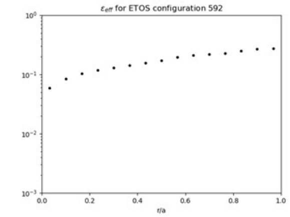
Neo-Classical Transport evaluation

- Consideration of ϵ_{eff} as a metric for neoclassical transport

$$D_e \propto \frac{\epsilon_{eff}^{3/2} T_e^{7/2}}{n_e B^2 R^2}.$$

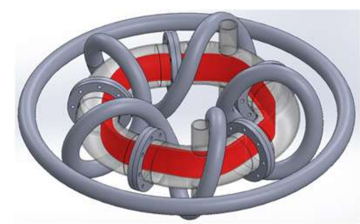
- Newly developed stellarator optimization code [2] used to calculate ϵ_{eff}
- Obtained ϵ_{eff} values are comparable to TJ-II, an existing mid-scale stellarator [3]





CAD model

- Use of Solid Works to model the device
  - Helical coil with diameter of 4 cm
  - Glass vessel with diameter of 10 cm
- 3D printed coil supports
- Vendor of the glass vessel identified



Summary and Outlook

Summary

- New stellarator design consisting of only one helical and one planar coil
- Design optimized for buildability using a cylindrical glass vessel
- Rotational transform and neoclassical transport estimates sufficient for a table-top experiment

Outlook

- Collaborate with the UW Mechanical Engineering Department for 3D printed coil supports
- Use existing infrastructure from a previous experiment "Helicotor"

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References

[1] H. Yamaguchi Nucl. Fusion 59 (2019)
[2] B. Faber, et al, PP11.00089 (2021)
[3] V. Tribaldos Physics of Plasmas 8, 1229 (2001)
[4] P. Helander et. al. Plasma Phys. Control. Fusion 54 (2012)