Assignment 1 & 2
Course 10401

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DTU

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Introduction

Assignment 1

TITLE Fusion power plant

GOAL Design a tokamak using a modified version of the model presented in Freidberg's book.

Assignment 2

TITLE Design of interferometer for DTU tokamak

GOAL # 1 To calculate the phase shift induced by O-mode radiation and investigate different microwave sources

GOAL # 2 To design a lens system to accommodate the beam propagation in the small DTU tokamak

Fusion power plant- Freidberg's model

Freidberg assumes a circular plasma cross section. Output parameters presented in the textbook are calculated given a few input parameters.

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Input parameters

Symbol	Quantity	
$n_{\text{flux fraction}}$	n flux in breeder end/n flux in breeder start	[]
C_F	Fixed cost propotionality constant	[$]
C_I	Nuclear island cost propotionality constant	$\left[\$ \cdot W/m^3 \right]$
P_E	Desired output power	[MW]
P_W	Maximum wall load	$\left[MW/m^2 \right]$
$B_{\max}$	Magnetic field at the edge of the coil	[T]
$\sigma_{\max}$	Tensile strenght of the magnetic field coils	[atm]
η_t	Energy conversion efficiency	[]

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OUTPUT PARAMETERS

Symbol	Quantity	Obtained values	
b	Blanket-and-shield thickness	1.2037	m
c	Magnet coil thickness	0.7993	m
a	Minor radius	2.0098	m
R_0	Major radius	4.9583	m
A	Aspect ratio	2.4670	[]
A_p	Plasma surface	393.4152	m^2
V_p	Plasma volume	395.3509	m^3
P_{dens}	Power density	4.9685e06	W/m
p	Plasma pressure	7.3672e05	Pa
n	Particle density	1.5327e20	$1/m^3$
B_0	Magnetic field at magnetic axis	4.5744	T
β	Normalised plasma pressure	8.85	$\%$
$\tau_{E_{\min}}$	Min confinement time for $(p \times \tau_E)_{\min}$	1.1415	s

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Model sensitivity

P_E, P_W, B_{max} and σ_{max} are changed. Many output parameters were unaffected or changed linearly. But some interesting results were found.

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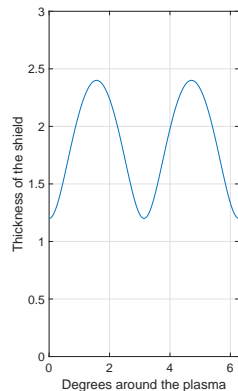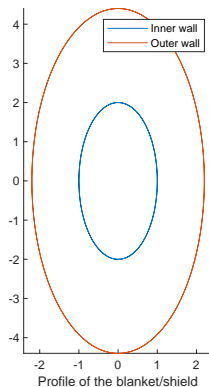Diagnostic Interferometer
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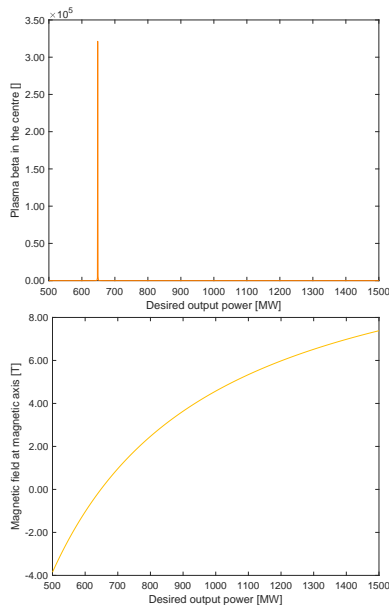
ELLIPTIC PLASMA-CHANGES IN MODEL

Now the plasma is modeled as an ellipse. The thickness of the blanket is not constant. Rather the outer and inner ellipses are kept as true ellipses.

$$V_l = 2\,\pi^2\,R_0\left((a_{\min} + b + c)^2 - a_{\min}^2\right)\kappa \quad (1)$$

$$c = \frac{2\,\xi}{1 - \xi}\left(\kappa\,a_{\min} + b\right) \quad (2)$$

Profile of the blanket/shield

Degrees around the plasma

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ELLIPTICAL MODEL OUTPUT PARAMETERS

Symbol	Quantity	Obtained values
c	Magnet coil thickness	1.30 m↑
A_p	Plasma surface	1210 m²↑
V_p	Plasma volume	793 m³↑
P_{dens}	Power density	2.48×10^6 W/m↓
p	Plasma pressure	5.20×10^5 Pa↓
n	Particle density	1.08×10^{20}/m³↓
β	Normalised plasma pressure	6.17%↓
$\tau_{E_{\min}}$	Min confinement time for $(p \times \tau_E)_{\min}$	1.62 s↑

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Symbol	Quantity	Obtained values
b	Blanket-and-shield thickness	1.20 m
c	Magnet coil thickness	1.30 m
a	Minor radius	2.01 m
R_0	Major radius	9.95 m↑
A	Aspect ratio	4.95↑
A_p	Plasma surface	2.41×10^3 m²↑
V_p	Plasma volume	1.59×10^3 m³↑
P_{dens}	Power density	2.48×10^6 W/m
p	Plasma pressure	5.20×10^5 Pa
n	Particle density	1.08×10^{20}/m³
B_0	Magnetic field at magnetic axis	8.80 T↑
β	Normalised plasma pressure	1.69%↓
$\tau_{E_{\min}}$	Min confinement time for $(p \times \tau_E)_{\min}$	1.62 s

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DEMO output parameters with $\kappa = 2$ and $A = 3$

Symbol	Quantity	Obtained values
b	Blanket-and-shield thickness	$1.20\,\text{m}$
c	Magnet coil thickness	$1.30\,\text{m}$
a	Minor radius	$2.01\,\text{m}$
R_0	Major radius	$6.03\,\text{m} \downarrow$
A	Aspect ratio	$3 \downarrow$
A_p	Plasma surface	$1.46 \times 10^3\,\text{m}^2 \downarrow$
V_p	Plasma volume	$962\,\text{m}^3 \downarrow$
P_{dens}	Power density	$4.01 \times 10^6\,\text{W/m} \uparrow$
p	Plasma pressure	$6.68 \times 10^5\,\text{Pa} \uparrow$
n	Particle density	$1.39 \times 10^{20}/\text{m}^3 \uparrow$
B_0	Magnetic field at magnetic axis	$6.07\,\text{T} \downarrow$
β	Normalised plasma pressure	$4.55\% \uparrow$
$\tau_{E_{\min}}$	Min confinement time for $(p \times \tau_E)_{\min}$	$1.26\,\text{s} \downarrow$

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DEMO WITH κ AND A AS FREE PARAMETERS

We have chosen to optimise the engineering volume and β using κ and A as free parameters. This yields optimum R_0 and κ

$$R_0 = \sqrt{a^3/b} \qquad (3)$$

$$\kappa = \frac{6\,a_{\min}\,\xi - b\,\xi - 6\,a_{\min} - b}{2\,a_{\min}\,\xi} \qquad (4)$$

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DEMO OUTPUT PARAMETERS WITH κ AND A AS FREE PARAMETERS

Symbol	Quantity	Obtained values
b	Blanket-and-shield thickness	$1.20\,\text{m}$
c	Magnet coil thickness	$1.30\,\text{m}$
a	Minor radius	$2.01\,\text{m}$
R_0	Major radius	$2.60\,\text{m}\downarrow$
A	Aspect ratio	$1.29\downarrow$
A_p	Plasma surface	$630\,\text{m}^2$
V_p	Plasma volume	$414\,\text{m}^3\downarrow$
P_{dens}	Power density	$9.49\times10^6\,\text{W/m}\downarrow$
$p\downarrow$	Plasma pressure	$1.02\times10^5\,\text{Pa}$
n	Particle density	$2.12\times10^{20}/\text{m}^3\downarrow$
B_0	Magnetic field at magnetic axis	$-3.09\,\text{T}\downarrow$
β	Normalised plasma pressure	$26.9\%\uparrow$
$\tau_{E_{\min}}$	Min confinement time for $(p\times\tau_E)_{\min}$	$1.26\,\text{s}$

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$$n_e < n_c = \omega^2 \frac{\epsilon_0 \cdot m_{e0}}{e^2} \tag{5}$$

$$\omega^2 \frac{\epsilon_0 \cdot m_{e0}}{e^2} = \omega^2 \frac{8.85 \times 10^{-12}\,\text{F/m} \, 9.11 \times 10^{-31}\,\text{kg}}{1.60 \times 10^{-19}\,\text{C}} \tag{6}$$

$$\Downarrow$$

$$n_e < 0.000314\omega^2 \tag{7}$$

At densities of $10^{18}/\text{m}^3$ the minimum frequency is:

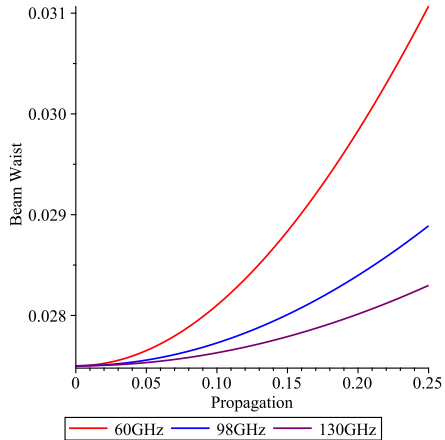$$\frac{\omega}{2\pi} > \frac{\sqrt{\frac{10^{18}/\text{m}^3}{0.000314}}}{2\pi} \tag{8}$$

$$\Downarrow$$

$$f \approx 9\,\text{GHz} \tag{9}$$

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Four Sources

At a density of $10^{18}/\mathrm{m}^3$ the minimum frequency of the wave is: $f \approx 9\,\mathrm{GHz}$

- ▶ 2.45 GHz
- ▶ 60 GHz (Transparent)
- ▶ 98 GHz (Transparent)
- ▶ 130 GHz (Transparent)

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Phaseshifts

Frequency [GHz]	Phase at $[2\pi]$	
	$n_e = 10 \times 10^{16}/m^3$	Phase at $n_e = 10 \times 10^{18}/m^3$
2.45	0.8620	86.17
60	0.0352	3.519
98	0.0215	2.154
130	0.0162	1.624

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GAUSSIAN TELESCOPE

- Input parameters:
  $w_0 = 0.0275\,\text{m}$, $freq = 60\,\text{GHz}$,
  $d_0 = 0.200\,\text{m}$, $f_0 = 0.250\,\text{m}$,
  $f_1 = 0.200\,\text{m}$

- Output distances:
  $d_1 = 0.220\,\text{m}$, $d_2 = 0.230\,\text{m}$,
  $d_3 = 0.230\,\text{m}$

- Output beamwaists:
  $w_1 = 0.0145\,\text{m}$, $w_2 = 0.0220\,\text{m}$

- Wavelenght: $\lambda = 0.005\,00\,\text{m}$

Beam Waist In A Gaussian Beam Interferometer

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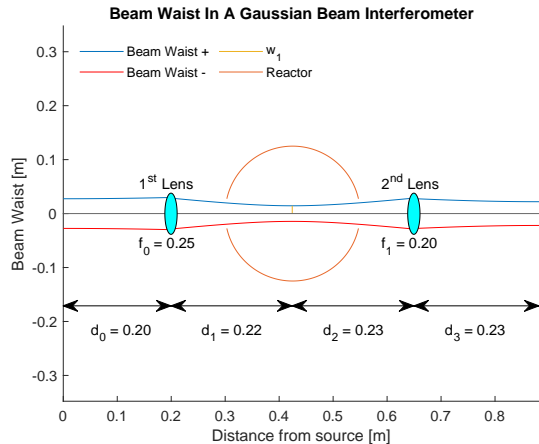
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