Assignment 1 & 2

Course 10401

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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.

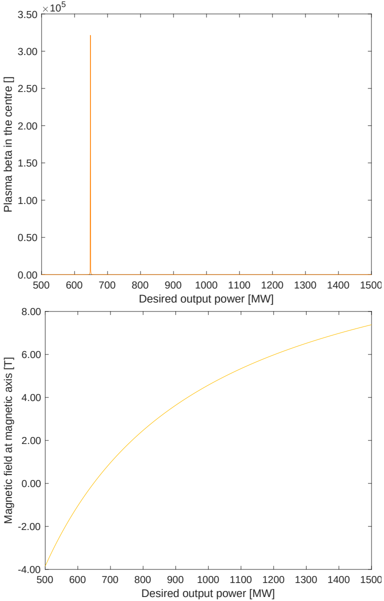
Input parameters

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	$\left[\$ \cdot \mathrm{W/m^3}\right]$
P_E	Desired output power	[MW]
P_W	Maximum wall load	$\left[\mathrm{MW/m^2}\right]$
$B_{\max}$	Magnetic field at the edge of the coil	[T]
$\sigma_{\max}$	Tensile strenght of the magnetic field coils	[atm]
η_t	Energy conversion efficiency	[]

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

P_{E}, P_{W}, $B_{\max}$ and $\sigma_{\max}$ are changed. Many output parameters were unaffected or changed linearly. But some interesting results were found.

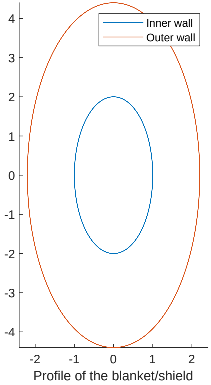


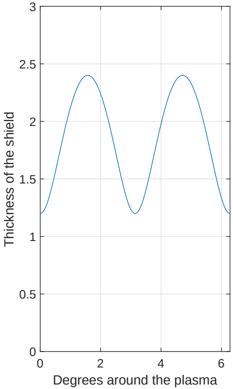
Elliptic plasma-changes in model

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.

$$V_\mathsf{l} = 2\,\pi^2\,R_0\,((a_{\min} + b + c)^2 - a_{\min}^2)\,\kappa \quad (1)$$

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





Elliptical model output parameters

Symbol	Quantity	Obtained values
c	Magnet coil thickness	$1.30\,\mathrm{m}\uparrow$
A_p	Plasma surface	$1210\,\mathrm{m}^2\uparrow$
V_p	Plasma volume	$793\,\mathrm{m}^3\uparrow$
P_{dens}	Power density	$2.48 \times 10^6\,\mathrm{W/m}\downarrow$
p	Plasma pressure	$5.20 \times 10^5\,\mathrm{Pa}\downarrow$
n	Particle density	$1.08 \times 10^{20}/\mathrm{m}^3\downarrow$
β	Normalised plasma pressure	$6.17\%\downarrow$
$\tau_{E_{\mathrm{min}}}$	Min confinement time for $(p \times \tau_E)_{\mathrm{min}}$	$1.62\,\mathrm{s}\uparrow$

Symbol	Quantity	Obtained values
b	Blanket-and-shield thickness	$1.20\,\mathrm{m}$
c	Magnet coil thickness	$1.30\,\mathrm{m}$
a	Minor radius	$2.01\,\mathrm{m}$
R_0	Major radius	$9.95\,\mathrm{m}\uparrow$
A	Aspect ratio	$4.95\uparrow$
A_p	Plasma surface	$2.41 \times 10^3\,\mathrm{m}^2\uparrow$
V_p	Plasma volume	$1.59 \times 10^3\,\mathrm{m}^3\uparrow$
P_{dens}	Power density	$2.48 \times 10^6\,\mathrm{W/m}$
p	Plasma pressure	$5.20 \times 10^5\,\mathrm{Pa}$
n	Particle density	$1.08 \times 10^{20}/\mathrm{m}^3$
B_0	Magnetic field at magnetic axis	$8.80\,\mathrm{T}\uparrow$
β	Normalised plasma pressure	$1.69\%\downarrow$
$\tau_{E_{\min}}$	Min confinement time for $(p \times \tau_E)_{\min}$	$1.62\,\mathrm{s}$

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

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	6.03 m $\downarrow$
A	Aspect ratio	3 $\downarrow$
A_p	Plasma surface	1.46×10^3 m^2 $\downarrow$
V_p	Plasma volume	962 m^3 $\downarrow$
P_{dens}	Power density	4.01×10^6 W/m $\uparrow$
p	Plasma pressure	6.68×10^5 Pa $\uparrow$
n	Particle density	1.39×10^{20} /m^3 $\uparrow$
B_0	Magnetic field at magnetic axis	6.07 T $\downarrow$
β	Normalised plasma pressure	4.55% $\uparrow$
$\tau_{E_{\text{min}}}$	Min confinement time for $(p \times \tau_E)_{\text{min}}$	1.26 s $\downarrow$

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

$$R_0 = \sqrt{a^3/b} \tag{3}$$

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

DEMO output parameters with κ and A as free parameters

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	2.60 m $\downarrow$
A	Aspect ratio	1.29 $\downarrow$
A_p	Plasma surface	630 m^2
V_p	Plasma volume	414 m^3 $\downarrow$
P_{dens}	Power density	9.49×10^6 W/m $\downarrow$
$p \downarrow$	Plasma pressure	1.02×10^5 Pa
n	Particle density	$2.12 \times 10^{20}/\mathrm{m}^3$ $\downarrow$
B_0	Magnetic field at magnetic axis	-3.09 T $\downarrow$
β	Normalised plasma pressure	26.9% $\uparrow$
$\tau_{E_{\mathrm{min}}}$	Min confinement time for $(p \times \tau_E)_{\mathrm{min}}$	1.26 s

Cut off

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

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

$$\Downarrow$$

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

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

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

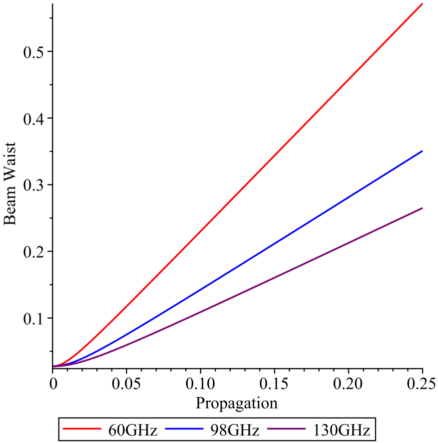
$$\Downarrow$$

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

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

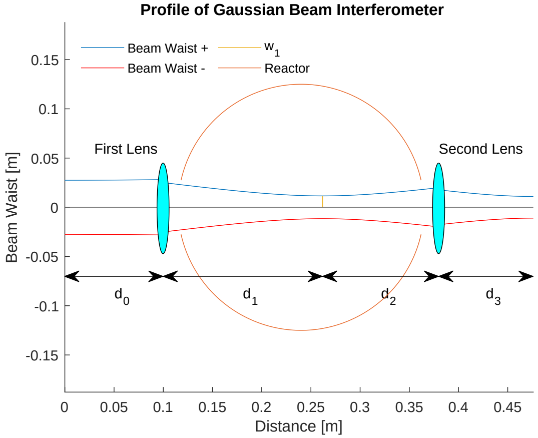


Phaseshifts

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

Gaussian Telescope

- Input parameters:
  w_0, $freq$, d_0, f_0, f_1
- Output distances:
  $d_1 = 0.1619$, $d_2 = 0.0881$, $d_3 = 0.0563$
- Output beamwaists:
  $w_1 = 0.0116$, $w_2 = 0.0069$
- Wavelenght: $\lambda = 0.005$



Questions

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