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Fokker-Planck Modelling of ECCD for NTM Stabilisation in ITER

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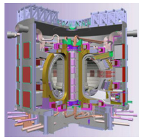


Abstract

•Ray tracing and Fokker-Planck code BANDIT-3D used to study the capability of the ITER ECRH upper launcher to stabilise neo-classical tearing modes (NTMs) of low rational order (m/n=2/1, 3/2) by means of localised ECCD.

•Effect of *local* n_e and T_e on:
1) optimal launch angles
(⇒ indications for the steering range required for the antenna)
2) figures of merit for NTM stabilisation, I/d and I/d²
(⇒ indications for power requirement)

•Comparison upper and lower row of mirrors

•Non-linear effects at high gyrotron power

BANDIT-3D

3D relativistic and self-consistent ray tracing and Fokker-Planck (FP) code [1-2]

Input

Trapping -important for NTMs because q=3/2 and q=2 surfaces close to plasma boundary- modelled in a realistic up-down asymmetric single null divertor configuration imported from EFIT equilibrium for ITER "scenario 2" (Q=10 ELMy H-mode, 15MA, inductive, B_0=5.3T, T_{e0}=24.8keV, n_{e0}=1.02 x $10^{20}m^{-3}$) converted in B_R,B_Z,B_ϕ on an R, z grid.
Profiles of n_e, T_e and Z_{eff} imported from ASTRA and replaced with profiles of increased resolution in the interesting range, ρ=0.5-1.

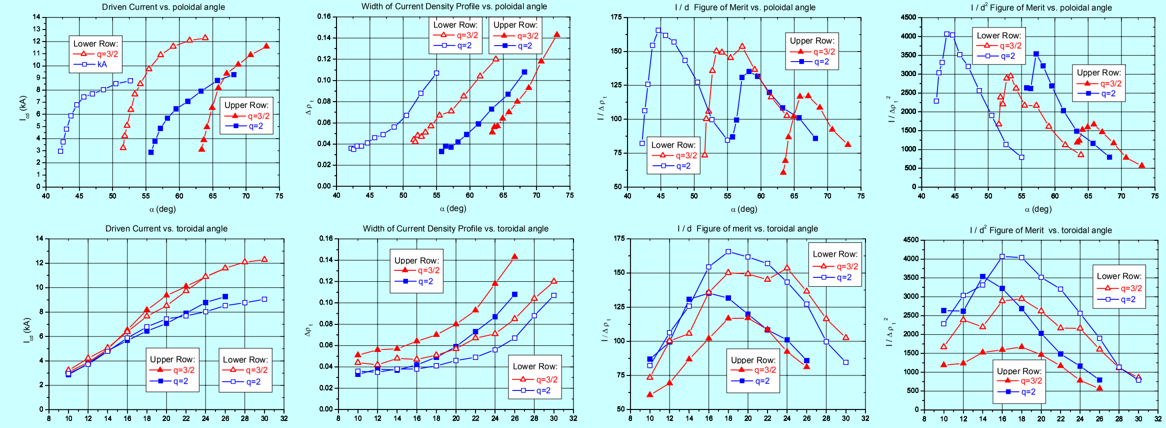
Ray tracing part

Cold dielectric tensor is retained in the conventional, WKB ray tracing.
Warm terms used for absorption.
Relativistic absorption allowed near EC harmonics.

FP part

2-stage operator-splitting algorithm to time-advance FP equation for f (v, θ, ρ) including:
1. e-e and e-i collisions
2. Ohmic heating by the loop voltage
3. quasilinear diffusion, using wave input from the ray tracing
4. trapped electron effects
5. relativistic effects
Diffusive and convective radial transport can also be included (not done here).

Launch Angle Optimisation vs. I/d and I/d2



"Regula falsi" to find beams hitting q=2, 3/2 surfaces

Among them, those yielding maximum I/d and I/d² were selected

Max over β is broader

Steep fall-off at low α

Upper/Lower Row Comparison for various n_e and T_e:

Δn_e	$\frac{(I/d)_U}{(I/d)_L}$	$\frac{(I/d^2)_U}{(I/d^2)_L}$
-30%	83%	78%
-15%	78%	67%
0	81%	87%
+15%	80%	72%
+30%	86%	73%

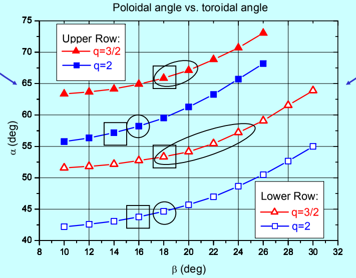
ΔT_e	$\frac{(I/d)_U}{(I/d)_L}$	$\frac{(I/d^2)_U}{(I/d^2)_L}$
-30%	95%	96%
-15%	85%	84%
0	81%	87%
+15%	74%	71%
+30%	72%	67%

Δn_e	$\frac{(I/d)_U}{(I/d)_L}$	$\frac{(I/d^2)_U}{(I/d^2)_L}$
-30%	70%	54%
-15%	71%	56%
0	76%	57%
+15%	75%	60%
+30%	71%	60%

ΔT_e	$\frac{(I/d)_U}{(I/d)_L}$	$\frac{(I/d^2)_U}{(I/d^2)_L}$
-30%	80%	58%
-15%	76%	51%
0	76%	57%
+15%	76%	56%
+30%	74%	56%

○ =highest I/d
(modulated CD)

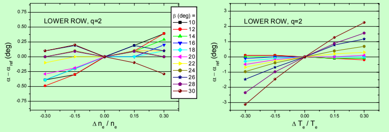
□ =highest I/d²
(NON-modulated CD)



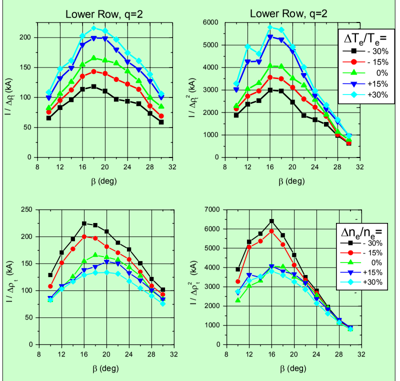
Effect of change of n_e and T_e

Given profiles rescaled by a factor between 0.7 and 1.3

Effect on optimal α at fixed β



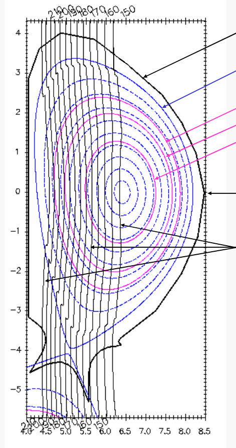
Effect on I/d and I/d²



Plots here refer to q=2 lower row

Similar results in Ref.[6] for q=3/2 lower row
q=2 upper row
q=3/2 upper row

Geometry



First wall

Separatrix

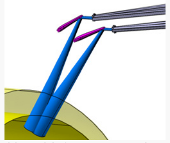
q=2
q=1.5
q=1

plasma midplane,
(Δz=+0.681m from *machine* midplane)

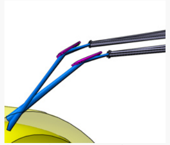
EC resonances
for various frequencies

Angle definitions:
α= *poloidal* launch angle
(standard: between midplane and poloid.projection of beam axis)

β= *toroidal* launch angle
(NON-standard def.:
angle between beam axis and its poloid.projection)



U and L beam targeting the q=3/2 surface



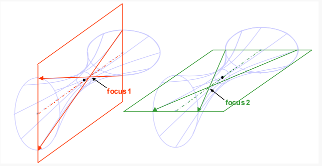
Same for q=2 surface
(courtesy of A.G.A.Verhoeven, FOM)

Astigmatic Beam Modelling:

8 angularly equidistant groups of 20 coplanar, equidistant rays

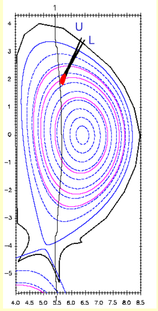
Different geometrical optics approximation (focus and angular aperture) in each of the 8 planes.

For example:



Focal spread= 171 and 284mm for U and L row, comparable with beam length (~1.5m)

Multiple beams and non-linear corrections at high power



We select beams with highest I/d² from lower (L) and upper (U) Row and compare results for separated (L, U) and simultaneous (L+U) launch.

	beta	alpha	Drho	j(rho)	I	I/d	I/d^2
	deg	deg		kA/m2	kA	kA	MA
q=2							
L	16	49.5	0.023	8.6	5.2	225	9.77
U	16	55.6	0.030	6.6	5.2	174	5.81
L+U			0.025	15.7	10.6	424	16.96
10+10MW			0.025	156.0	106.0	4240	169.60
q=3/2							
L	16	60.0	0.033	7.3	5.7	173	5.25
U	18	66.0	0.047	7.4	7.8	165	3.51
L+U			0.038	13.6	12.6	332	8.73
10+10MW			0.038	136.0	126.0	3316	87.26
q=1							
L	16	69.9	0.072	6.6	8.0	112	1.55
U	16	72.7	0.087	5.4	7.7	89	1.02
L+U			0.081	11.8	16.0	198	2.44
10+10MW			0.081	119.0	161.0	1988	24.54

Summary and Conclusions

•Realistic *beam* geometry: virtual rotation point + astigmatic corrections

•Realistic *plasma* geometry ⇒ realistic trapping estimations, which in turn is important for NTMs

•Upper row of mirrors yields broader deposition and thus worse I/d and I/d² than lower row.

•J profiles from L and U *additive*

•J *linear* with power up to 10MW/beam

} ⇒ 8 beams combined yield a localised I_{cd} that increases linearly with power

•n_e effect on α,β negligible; T_e effect up to 1deg

•n_e, T_e effect on I/d and I/d² in accord with ECCD efficiency ~T_e/n_e

Acknowledgements
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