33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-1.117 (2006)

Evaluation of ITER magnetic shear control possibilities using MICCD

M. Laxåback[1,2] and T. Hellsten[2]

[1] *EFDA-JET Close Support Unit, Culham Science Centre, Abingdon, OX14 3DB, UK*

[2] *Div. of Fusion Plasma Physics, Association EURATOM-VR, Alfvén Laboratory, School of Electrical Engineering, KTH, 100 44 Stockholm, Sweden*

Active sawtooth period control using minority ion cyclotron current drive, MICCD, has been proposed for ITER in order to avoid having neoclassical tearing modes triggered by long-period, large-amplitude, sawteeth. In this paper we evaluate the magnetic shear modification that is possible with the proposed ITER MICCD scheme, which uses a ^{3}He minority, and compare that to an alternative scheme which uses a H minority. MICCD drives two main current components; current carried by Doppler-resonant ions in passing orbits that have been heated to energies with lower bulk plasma collisionalities [1] and current carried by ions in broad trapped orbits [2]. The choice of minority is important primarily due to the difference in back current, i.e. the current carried by electrons dragged along by the minority ions and by the bulk plasma that flows opposite to the minority ions due to momentum conservation. The relationship between the total driven current and the minority current is given by [3]:

$$J_{tot} = J_{min}\left(1-\frac{Z_{min}}{Z_{eff}} - \frac{\lambda m_{min}\sum_i Z_i n_i\left(1-\frac{Z_i}{Z_{eff}}\right)}{Z_{min}\sum_i n_i m_i} + f_t A(Z_{eff})\left(\frac{Z_{min}}{Z_{eff}} - \frac{\lambda m_{min}\sum_i n_i Z_i^2}{Z_{min} Z_{eff}\sum_i n_i m_i}\right)\right) \quad (1)$$

f_t is the trapped particle fraction [4], $\lambda = 1$ and $\lambda = 0$ for current carried by ions in respectively passing and trapped orbits and $A(Z_{eff}=1.66) \approx 1.4$ takes into account friction with trapped electrons. The drag current corrections for the scenario presented below are illustrated in Fig. 1.

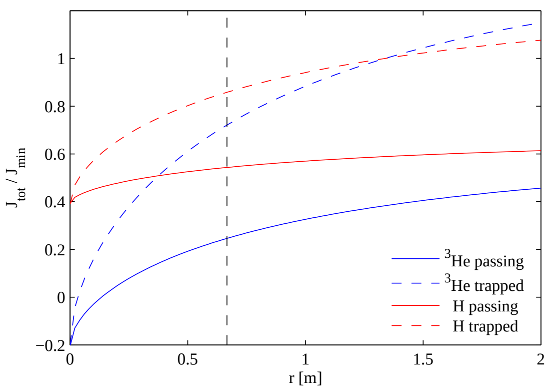

Figure 1: Drag current correction. The vertical dashed line indicates the $q = 1$ surface.

MICCD modelling has been performed with the SELFO code [5, 6] for an ITER-like DT plasma [6] with the following parameters: $R_0 = 6.2\,\mathrm{m}$, $a = 2.0\,\mathrm{m}$, $B_0 = 5.3\,\mathrm{T}$, $I_p = 12\,\mathrm{MA}$, $P_{NBI} = 26.4\,\mathrm{MW}$, $T_i = T_e = 20\,[1-0.15(r/a)^2]^{12}\,\mathrm{keV}$, $n_{e0} = 1.25\times10^{20}[1-0.999(r/a)^2]^{0.25}\,\mathrm{m}^{-3}$, $n_{T0} = n_{D0} = 4.9\times10^{19}\,\mathrm{m}^{-3}$, $n_{^9_4Be0} = 2.5\times10^{18}\,\mathrm{m}^{-3}$, $n_{^4He0} = 5\times10^{18}\,\mathrm{m}^{-3}$, $n_{^{40}_{18}Ar0} = 1.25\times10^{17}\,\mathrm{m}^{-3}$ and $Z_{eff} \approx 1.66$. $J_p \propto [1-0.98(r/a)^2]^{0.5}\,\mathrm{Am}^{-2}$, which places the $q = 1$ surface close to $r/a = 1/3$, and the DT fusion yield comes to 320 MW. With the circular cross section used in SELFO the central current, power and α-particle source densities are similar to those in ITER with $I_p \approx 15$ MA, $P_{NBI} \approx 33$ MW and $P_{FUS} \approx 400$ MW. Also note that a simulated P_{RF} of 16 MW corresponds to $P_{RF} \approx 20$ MW in ITER.

Table 1 shows the steady-state power partition on resonant species for the $\pm 90^\circ$ antenna phasings with 2% ^{3}He (48.6 MHz) or H (73 MHz) minorities and the cyclotron resonances tangent to the $q = 1$ surface on the low field side. Notable is that the T damping increases with power due to the formation of a high-energy tail and that the parasitic absorption on α-particles is low.

[%]	^{3}He - 16 MW		^{3}He - 32 MW		^{3}He - 48 MW		H - 16 MW	
Species	-90°	$+90^\circ$	-90°	$+90^\circ$	-90°	$+90^\circ$	-90°	$+90^\circ$
e^-	13	12	12	11	11	11	4	3
^{3}He	70	64	65	55	55	57	—	—
H	—	—	—	—	—	—	58	54
T	14	21	22	33	33	31	0	1
D	2	2	1	0	1	1	25	31
^{4}He	1	1	0	0	0	0	13	11

Table 1: Power partition during ^{3}He and H MICCD. The values for D and ^{4}He include the power absorbed by beam ions and α-particles.

Figs. 2 and 3 show the driven current densities and the shear modification that can be expected in ITER when using the full installed power (20 MW) for ^{3}He MICCD. Note that the current driven by ions in broad trapped orbits is comparable to that by ions in passing orbits and that the magnetic shear modification is small. If the power is increased further, Figs. 4 and 5, more resonant ^{3}He ions are driven into trapped orbits, curtailing the current driven by ions in passing orbits.

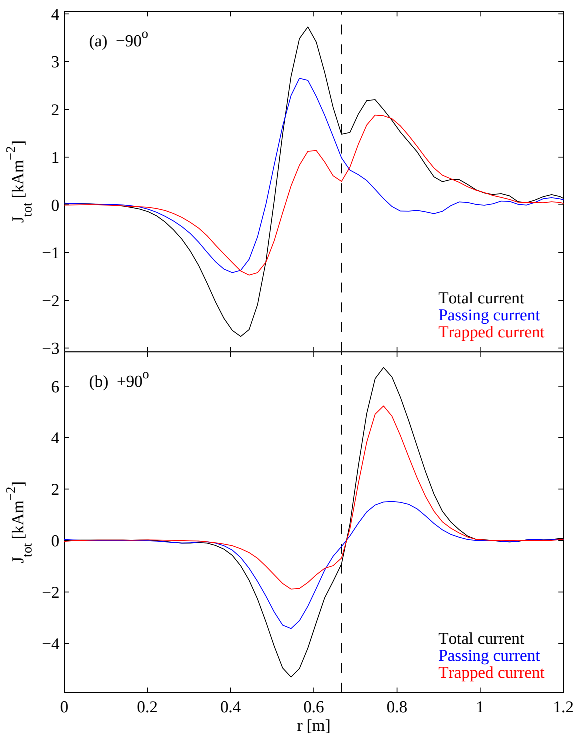

Figure 2: Current densities driven with 16 MW of ^{3}He MICCD.

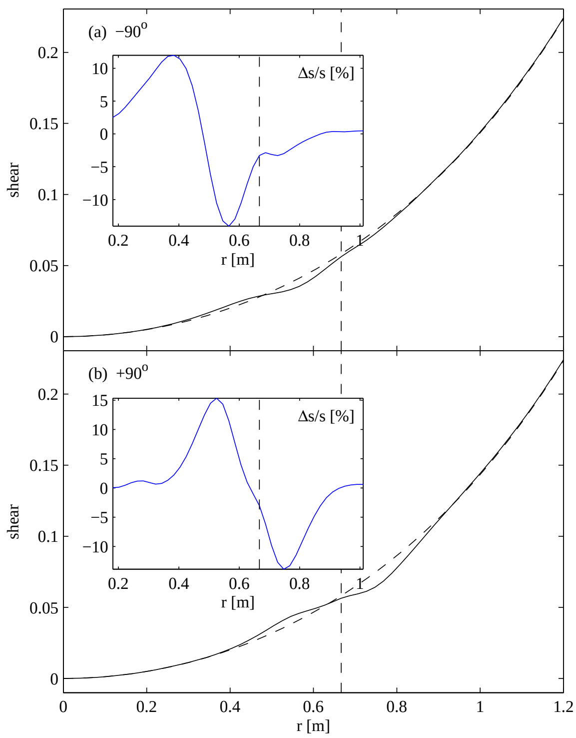

Figure 3: Modification to the magnetic shear. Inserted graph shows the relative changes.

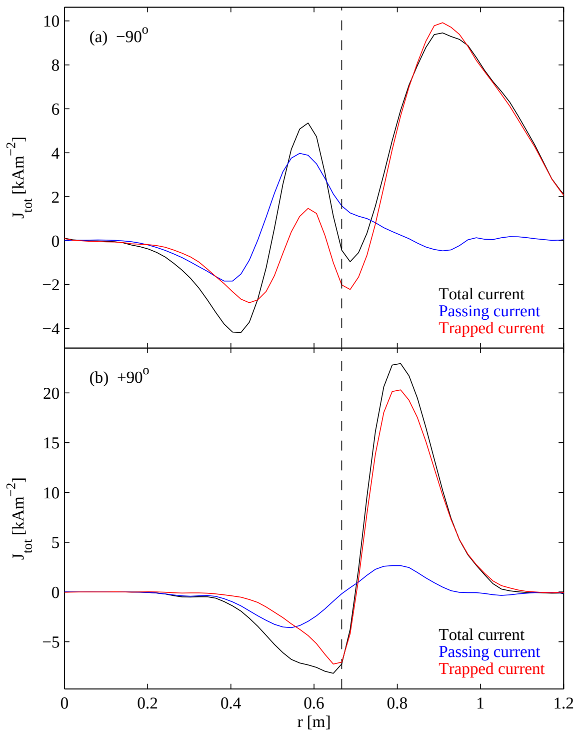

Figure 4: Current densities driven with 32 MW of ^{3}He MICCD.

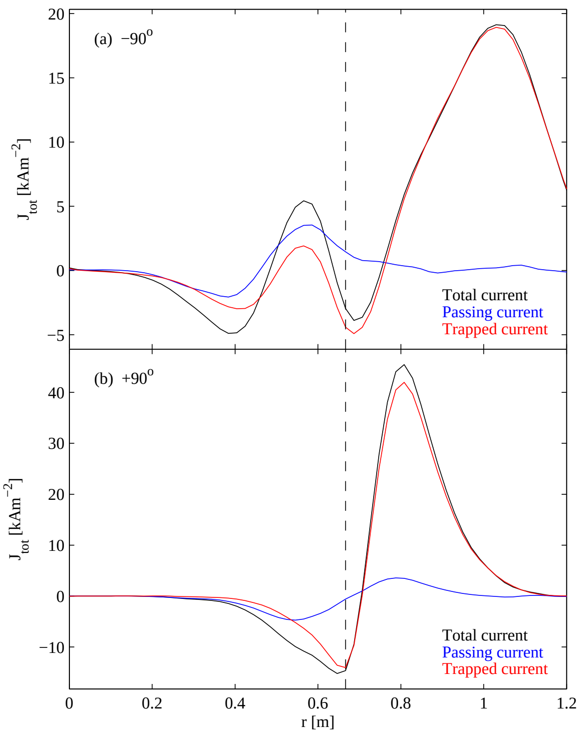

Figure 5: Current densities driven with 48 MW of ^{3}He MICCD.

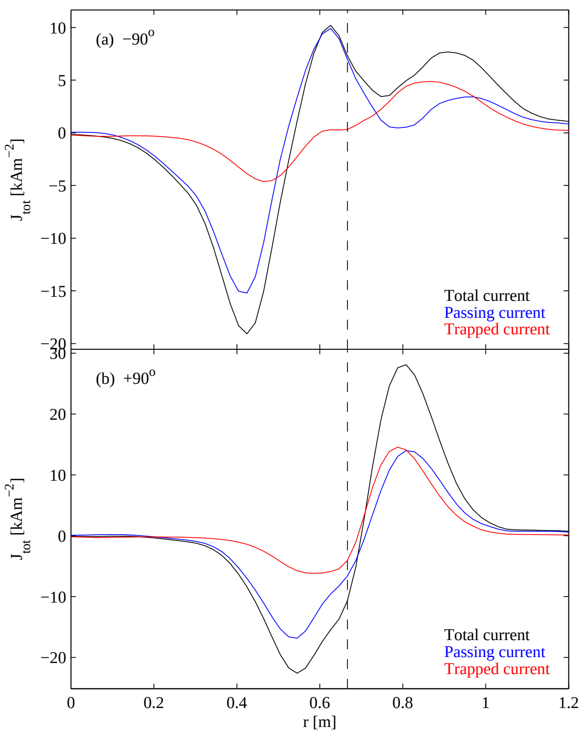

Figure 6: Current densities driven with 16 MW of H MICCD.

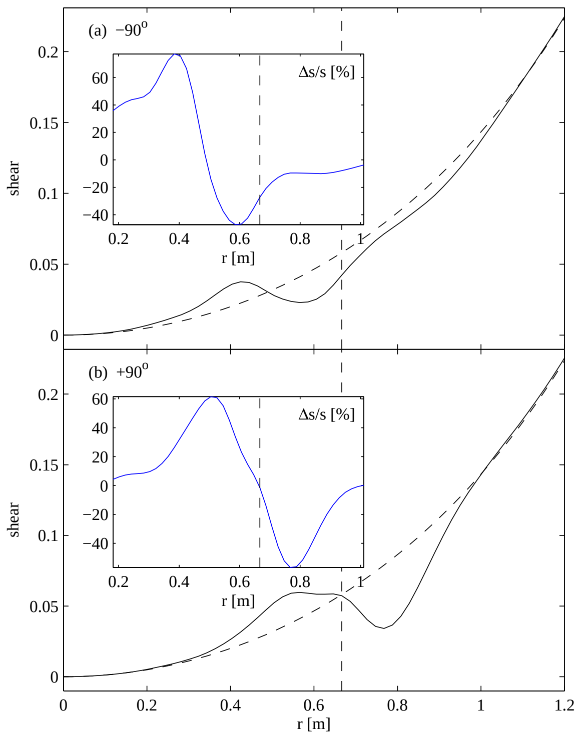

Figure 7: Modification to the magnetic shear from 16 MW of H MICCD.

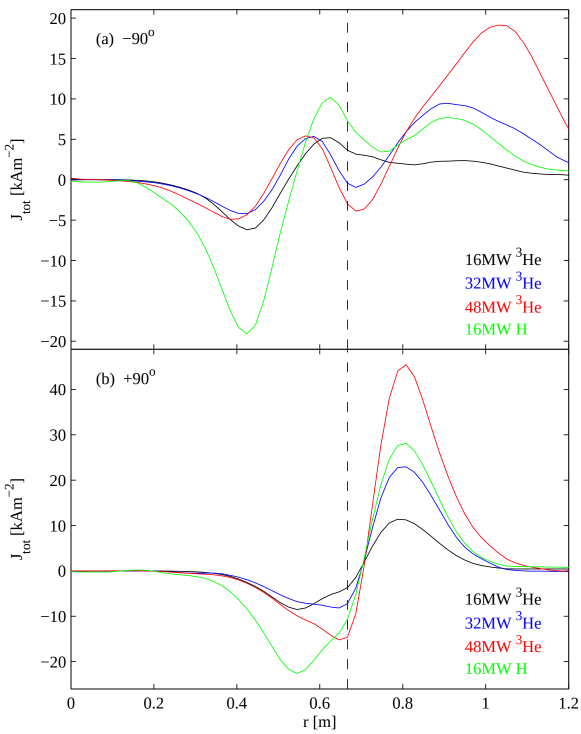

Figure 8: MICCD current densities.

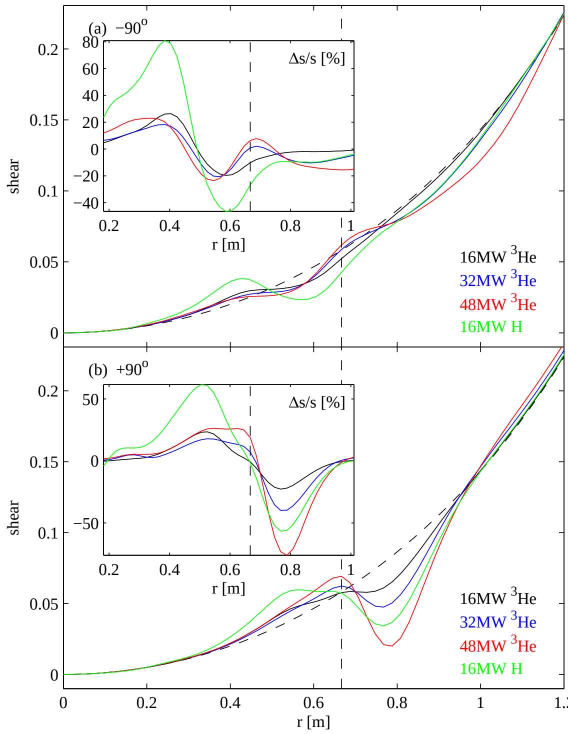

Figure 9: Magnetic shear modification.

Figs. 6 and 7 show the driven currents and the shear modification of the alternative H MICCD scheme. With the smaller back current and larger fast ion population due to the lower collisionality of the faster H ions the current drive is significantly more efficient than with the ^{3}He scheme. This is further illustrated by the comparison in Figs. 8 and 9. Whereas ^{3}He MICCD is unlikely to work well in ITER even at unrealistically high levels of RF power, H MICCD could offer a viable scheme for magnetic shear modification already at the nominally installed power. A more thorough analysis of MICCD in ITER can be found in Ref. [6].

References

[1] N.J. Fisch. Current generation by minority-species heating. *Nuclear Fusion*, 21(1):15, 1981.

[2] T. Hellsten, J. Carlsson, and L.-G. Eriksson. Minority ion cyclotron current drive in tokamaks. *Physical Review Letters*, 74(18):3612, 1995.

[3] V.P. Bhatnagar, D.F.H. Start, F. Chaland J. Jacquinot, A. Cherubini, and F. Porcelli. Local magnetic shear control in a tokamak via fast wave minority ion current drive: Theory and experiments at JET. *Nuclear Fusion*, 34(12):1579, 1994.

[4] P. Helander and D.J. Sigmar. *Collisional Transport in Magnetized Plasmas*. Cambridge University Press, 2002.

[5] J. Hedin, T. Hellsten, L.-G. Eriksson, and T. Johnson. The influence of fi nite orbit width on the ICRH heating in toroidal plasmas. *Nuclear Fusion*, 42(5):527, 2002.

[6] M. Laxåback and T. Hellsten. Modelling of minority ion cyclotron current drive during the activated phase of ITER. *Nuclear Fusion*, 45(12):1510, 2005.