An Enhanced ITER ECH Upper Port Launcher for an Extended Physics Programme

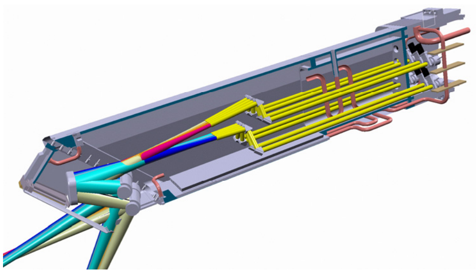
M.A. Henderson[1], *D. Campbell*[2], *R. Chavan*[1], *D. Farina*[3], *E. Poli*[4], *G. Ramponi*[3], *G. Saibene*[2], *O. Sauter*[1], *H. Shidara*[1], *H. Zohm*[4], *C. Zucca*[1]

[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas, Association EURATOM-Confédération Suisse, CH-1015 Lausanne, Switzerland
[2] EFDA Close Support Unit, Boltzmannstrasse 2, D-85748 Garching, Germany
[3] Istituto di Fisica del Plasma, EURATOM- ENEA- CNR Association, 20125 Milano, Italy
[4] IPP-Garching, Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany

First Author e-mail: mark.henderson@epfl.ch

The ITER ECH heating and current drive system consists of 24MW at 170GHz, which can be directed to either the equatorial or upper port launching antennas (launchers) depending on the desired physics application. The upper launcher reference design[1,2] (UL), see figure 1a, uses a front steering (FS) mirror[3] that sweeps the beam in a poloidal plane providing co-ECCD over the range of $0.64 \leq \rho_\psi \leq 0.93$. The launcher has a single dedicated purpose of stabilising the neoclassical tearing modes (NTM), with the launcher steering range accessing the region in which the q=3/2 or 2 flux surfaces are expected to be found for scenarios susceptible to NTM[4], see figure 1b. The FS launcher focuses the RF beam to a small spot size near the resonance surface, with the deposition width (w_{CD}) the order of marginal island width (w_{marg}) and the maximum current density (j_{CD}) exceeding the local bootstrap current density (j_{BS}). The performance of the FS launcher far exceeds (by a factor of 1.5 to 3)[5] that required by the physics to stabilize the NTM, where the NTM stabilization figure of merit (defined as $\eta_{NTM}=j_{CD}/j_{BS}$) should be $\eta_{NTM} \geq 1.2$ for complete NTM stabilisation[4].

a)



b)

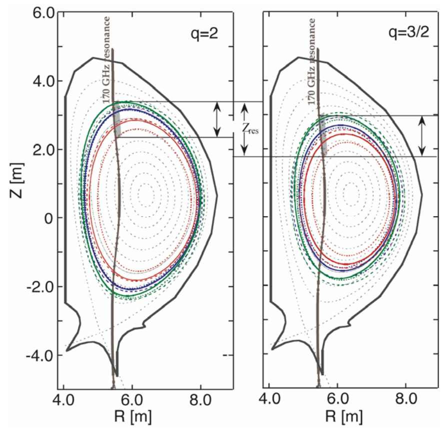


Figure 1: a) The ITER ECH upper launcher shown in a port plug and b) the range of q=2 and 3/2 flux surfaces that the UL is required to access for NTM stabilisation.

The two mirror (focusing and steering) system of the FS launcher essentially decouples the steering and focusing functions of the FS launcher. This design feature offers the flexibility to increase the steering range beyond that required by the NTM stabilization such that the launcher can access further inward (for control of the sawteeth) or further outward (for control of the ELMs). Note that the steering range is mainly limited by the onset of cyclic fatigue of the steering mechanism components[3] and by the allowable size of the cutout in the first wall panel (to limit the potential radiation damage to the steering mechanism as well as neutron streaming into the surrounding vacuum vessel and poloidal field coil structures).

An alternative method to increase the steering range is to shift the relative deposition region of the two steering mirrors of a given launcher to span a larger section in the plasma with an overlap region between the two steering ranges. For example, the upper steering mirror (USM) can be made to access further inward (or the lower steering mirror (LSM) further outward) as illustrated figure 2a. The region accessible from the upper port launcher is extended from the zone limited by just the NTMs to nearly double that size to include the EP (extended physics) zones as shown in figure 2a. Note that the rotation of each steering mirror is reduced to ±5.5º (from >±6º) to reduce cyclic fatigue; the USM covers a larger region than the LSM due to geometric arrangement of the launch and the deposition locations. The mm-wave optics are independent for each steering row such that the beam waists are optimized for a maximum j_{CD} in the respective zones in the plasma, as shown in figure 2b.

a) b)

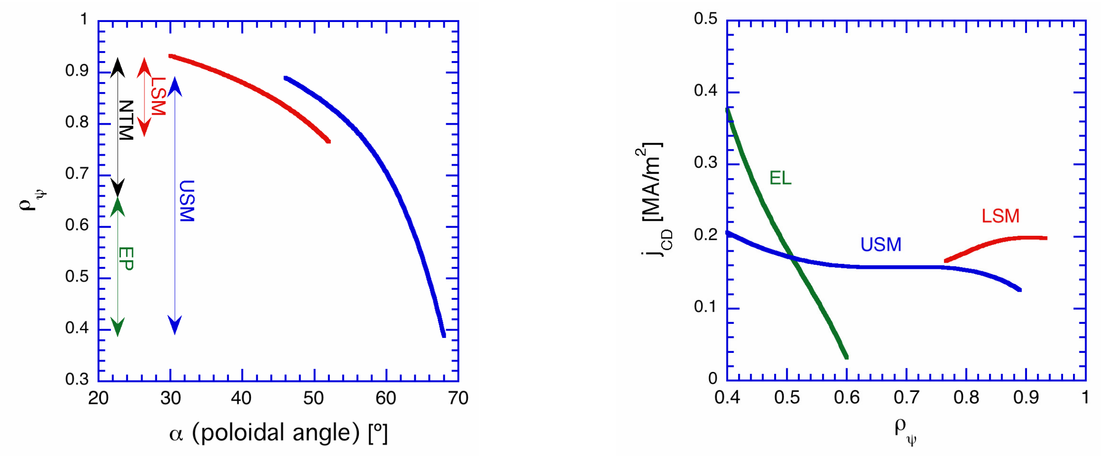


Figure 2 (a) Extension of the total access range (ρ_ψ=0.4 to 0.93) of the upper (USM) and lower (LSM) steering mirrors from the zone of NTMs (ρ_ψ=0.64 to 0.93) by partial overlapping of the two steering mirrors access ranges. (b) Comparison of j_{CD} between either the two steering mirrors of the UL with 13.3MW and the EL launcher (EL) with 20MW.

The equatorial launcher[6] (EL) has the beams scanned in a toroidal plane to provide an increased total driven current, as a result the beams become very broad with increasing ρ_ψ (which corresponds to a large toroidal injection angle). The resulting j_{CD} rapidly drops off such that the UL provides a larger j_{CD} in the region of $0.5 \leq \rho_\psi \leq 0.65$, thus offering an improved performance over that of the EL in this region for applications requiring a large j_{CD} such as sawtooth control (when the q=1 surface occurs in this region). Note that the calculated current densities used a single beam to represent the four (UL) or eight (EL) beams per steering mirror. A total of 13.3MW (20MW) in the UL (EL) steering mirrors was used.

Extending the range of the UL can relax the EL steering range down to $0 \leq \rho_\psi < 0.5$ (equivalent range as the extended range of the UL). Note that outside of $\rho_\psi \sim 0.5$ the EL beams strongly refract resulting in less than 100% absorption. Reducing the steering range provides adequate flexibility to modify the EL launcher design, for example to add counter ECCD, which can be used to tailor a hollow current profile assisting in ITER scenarios of negative shear or provide pure heating (balancing co and counter-ECCD) with nearly zero current drive to avoid current profile peaking or flattening of the q profile to keep $q_{min} > 1$[7].

References

[1] G. Saibene *et al*, this conference.
[2] M. Henderson *et al*, Journal of Physics: Conference Series 25 (2005) 143-150.
[3] R. Chavan *et al*, this conference.
[4] H. Zohm *et al*, Journal of Physics: Conference Series 25 (2005) 234-242.
[5] G. Ramponi *et al*, Journal of Physics: Conference Series 25 (2005) 243-251.
[6] K. Takahashi *et al*, Journal of Physics: Conference Series 25 (2005) 75-83.
[7] M. Henderson *et al*, *Synergy Study of the Equatorial and Upper Port ITER ECH Launchers for an Enhanced Physics Performanc*e, EC-14, Santorini, Greece 2006.