Electron Cyclotron waves for Current Drive and Neo-Classical Tearing Mode mitigation in a DEMO machine

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Abstract — **In this paper we present preliminary results of the analysis on driving current and mitigating Neo-classical Tearing Mode instabilities, using Electron Cyclotron waves, as input for Port Plug development and integration in DEMO. The study has been carried out in a joint collaboration between the Karlsruhe Institute of Technology (Karlsruhe, Germany) and Max Planck Institute for Plasma Physics (Garching, Germany), within the EUROfusion Power Plant Physics and Technology activity. The assessment has been performed for a pulsed DEMO machine and it has been constrained by requirements imposed by tritium self-sufficiency and structural components integrity.**

I. INTRODUCTION

TO grant reliable plasma operation, the tokamak reactor DEMO requires the use of an Electron Cyclotron Resonance Heating and Current Drive (ECH&CD) systems for plasma assisted breakdown, ramp up/down, pure heating, impurities control, disruption control and to mitigate plasma instabilities like the sawtooth and the Neoclassical Tearing Mode (NTM).

The study we present in this paper is focused on the use of the ECH&CD system to control NTMs, expected to be potentially unstable at the q=2 and q=3/2 rational surfaces [1]. It is based on a DEMO model as given in [2] (pulsed machine). In particular in this study, we assumed a pulse flat top of 2 hours, a machine Aspect Ratio (AR) equal to 4.0, which implies 16 Toroidal Coils (TC) producing a field of 6.79T [2, 3]. As the project still lies in a pre-conceptual phase, this is one of the possible configurations presently considered: A reference design EU DEMO1-2015 with AR = 3.1 and 18 TC was recently released and was not considered yet in our study. The ECH&CD system, providing 50MW in the plasma, is expected to operate at frequencies above 200GHz [3].

II. ASSUMPTIONS

To assess consistently the ECH&CD launching system design, we have preliminary studied its efficiency for different beam waist, injected frequency, and injection angles and positions (both top and equatorial), assuming 36 waveguides certified for 2 MW, distributed in different Port Plugs.

The analysis, constrained by requirements imposed by tritium self-sufficiency and component structural integrity, has been performed with the beam-tracing code TORBEAM© [4, 5] to calculate the propagation and the absorption of the beams, and the transport code ASTRA© [6] used to calculate two kinetic profiles: a flat density profiles (ITER ELMy H-mode scenario [7]), and a peaked density profile (according to the ASDEX Upgrade improved H-mode scenario [8]). For NTM mitigation we have assumed a width of the ECCD profiles of 10-20 cm (depending on the profiles and the rational surface considered) [9].

III. BEAM TRACING ANALYSES

The first results for ECCD, as preliminarily presented in [10], are summarized in fig. 1 where the current (MA/MW) is shown as a function of selected gyrotron frequencies (170GHz, 204GHz, 238GHz, 272GHz).

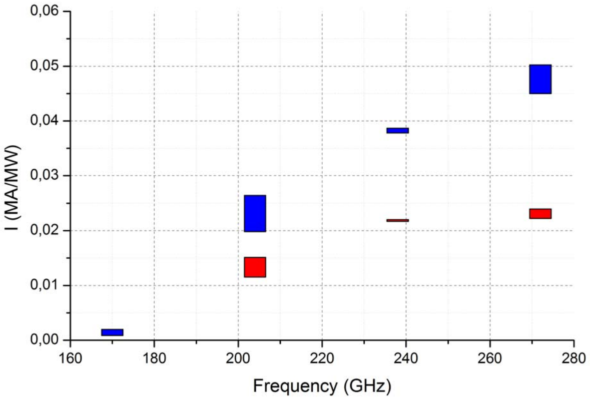

Fig. 1. ECCD efficiency for top injection for flat (blue) and peaked (red) density profiles, simulated for different injection positions (vertical spread).

As a following step, we computed as function of frequency f, the injection angles α and β, the deposition location of EC power absorption $\rho(f,\alpha,\beta)$, the driven current efficiency $\eta(f,\alpha,\beta)$, the absorbed power $P_{ABS}(f,\alpha,\beta)$, the total driven current $I_{CD}(f,\alpha,\beta)$ and the deposition profile width $\Delta\rho(f,\alpha,\beta)$. In this parameter space, we determined the relations between injection angles and deposition locations and between injection angles and current drive efficiencies, for different injection points (provided in R, Z) corresponding to waveguide termination and localized within the Port Ducts (Equatorial and Vertical).

Five injection position in both Vertical and Equatorial Port Plugs and a frequency scan (with a 10GHz step) between 170GHz and 250GHz, have been also considered, as well as angular scans in α and β (with a step of 5°), in order to cover a large portion of the plasma column.

Scope of the study has been to identify the most reliable injection positions and angles, in term of Current Drive efficiency, for ECH&CD launchers. In fig. 2, as *exemplum*, we show the results for q=3/2 in case of a flat density profile. The current density is plotted as function of the deposition width for different injection positions and frequencies. At 240GHz injecting at R=11.287m and Z=3.974m we obtain the maximum efficiency at α=64° and β=34°.

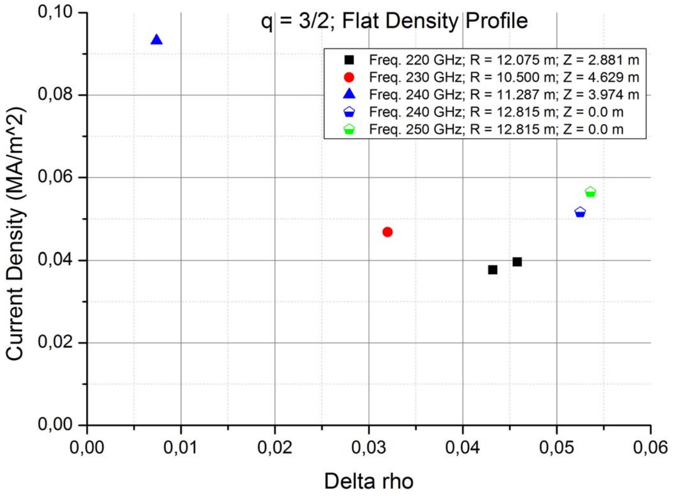

Fig. 2. Current density as function of the deposition width for different injection positions and frequencies for q = 3/2 for a flat density profile.

IV. PORT PLUG INTEGRATION

The results so far obtained have been used to start an assessment on the integration in DEMO of an Upper Ports (UP) à la ITER (shown in white in fig. 3), for hosting ECH&CD launchers dedicated to NTM mitigation. It is worth mentioning that presently DEMO foresees an Equatorial Port Plug (baseline) and a Vertical Port Plug (optional).

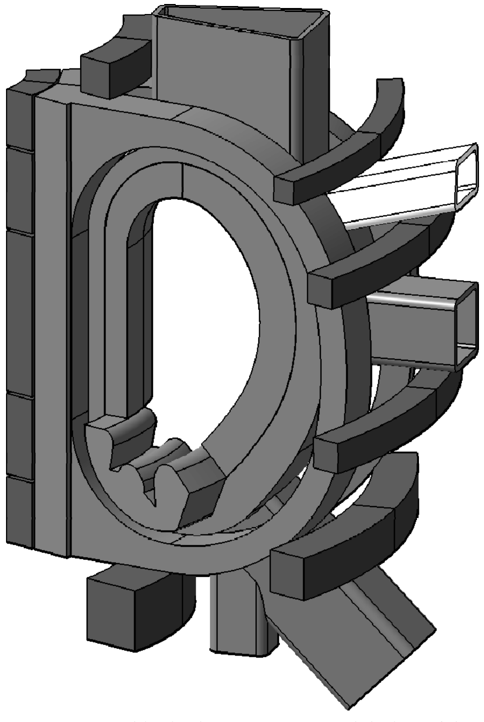

Fig. 3. DEMO sector. In white is shown a conceptual design of the UP

In the framework of this study, we included also the impact of Blanket openings required by the ECH&CD launchers on the Tritium Breeding Ratio (TBR). In particular this is depending on the breeder material employed, their size and number, and whether or not they are built with neutron absorbing and/or reflecting material [11].

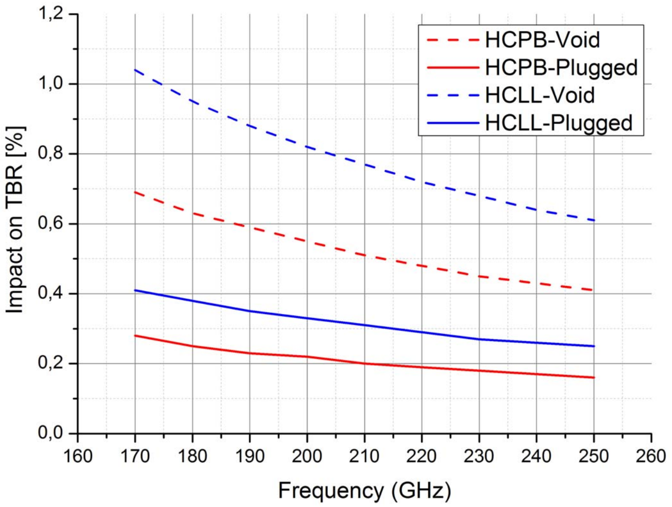

Fig. 4. Impact on TBR for HCPB (red) and HCLL (blue) blanket type and for plugged (solid) and void (dashed) openings

In fig. 4 we show a first estimation of the impact of 36 openings on TBR. Two blanket types have been considered: Helium Cooled Pebble Bed (HCPB) and Helium Cooled Lithium Lead (HCLL). The frequency dependence is due to the width of the openings, which takes into account the beam divergence (larger at lower frequencies). Results, although preliminary, are within the safety margin assumed in [11], i.e. 5% reduction due to port openings.

Combining the outcome of the beam tracing analyses and the impact on TBR assessment, and accounting for space limitation in the Vertical Port (dedicated to Remote Handling operations), limited amount of power dedicated to NTM control (10 MW) and advantages in terms of stabilization efficiency, the UP becomes an interesting option to work out ECH&CD launchers. Work will continue with the reference design DEMO1 2015

REFERENCES

[1]. S. Günter et al., Nucl. Fusion **38** (1998) 1431
[2]. F. Romanelli et al., EFDA Roadmap (2013)
[3]. J. Jelonnek et al., 9th International Workshop on Strong Microwaves and Terahertz Waves: Sources and Applications, Conf. Proc. 2014
[4]. E. Poli et al., 2001 *Fusion Eng. Des.* **53** 9
[5]. E. Poli et al., 2001 *Comput. Phys. Commun.* **136** 90
[6]. G. V. Pereverzev et al., 2002 ASTRA: Automated System for Transport Analysis in Tokamaks *IPP Report* 5/98 Max-Planck-Institut für Plasmaphysik
[7]. T. Casper *et al* 2010 *Proc. 23rd Int. Conf. on Fusion Energy (Daejeon, Republic of Korea, 2010)* (Vienna: IAEA) ITR/P1-19
[8]. A.C.C. Sips *et al* 2007 *Nucl. Fusion* **47** 1485
[9]. R. Wenninger et al., Advances in the Physics Basis for the European DEMO Design, Nuclear Fusion 55 (2015), 063003
[10]. G. Grossetti et al., 9th International Workshop on Strong Microwaves and Terahertz Waves: Sources and Applications, Conf. Proc. 2014
[11]. U. Fischer et al., *Neutronics Requirements for a DEMO Fusion Power Plant*, to be published in 2015 on Fus. Eng. & Des.

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