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INTRODUCTION

Electron Cyclotron (EC) beam injection systems are considered for ITER-FEAT and JET in scenarios for the control of both plasma current profile and MHD instabilities [1]. Quasi-optical designs of the EC launchers for ITER-FEAT and JET-EP devices are prepared to optimize the injection parameters and to obtain a well localized Electron Cyclotron Current Drive (ECCD) around the rational surfaces q=3/2 and q=2 in order to suppress the low-order activities, as Neoclassical Tearing Modes (NTMs), with m=3, n=2 and m=2, n=1. The basic feature of EC waves to propagate into the plasma without attenuation and interaction with the edge allow to locate the launching final mirrors far from the vessel especially in the case of ITER. A multiple beam tracing model is used to define feasible solutions for the injection schemes with optimized poloidal and toroidal beam steering angles. The beam width is maximised on the mirrors to lower diffraction losses and, taking into account the space constraints, each pair of beams is reflected on a single final mirror. In ITER-FEAT the proposed frequency for the NTMs stabilization is f=170GHz withRF injection from three upper ports and in JET f=113GHz from the low field side with the possibility to test also f=170GHz by using a multi-frequency scheme with the same mirrors and windows chosen for the lower frequency. In this paper we present the EC multi-beam launch for both the devices and we discuss the NTM stabilization obtained by current driven in the absorption zone of propagation of these beams around q=3/2 and q=2. A technical set-up of 6 gyrotrons, 1MW each is proposed for Electron Cyclotron Resonance Heating (ECRH) and ECCD in JET for a total injected EC power of about 5MW; 8 gyrotrons per launcher are supposed working at 1MW each in ITER-FEAT for NTM stabilization filling identical upper ports in different toroidal position.

1. MULTIPLE EC-BEAM INJECTION

1.1 JET

In JET 6 gyrotrons are expected to inject the RF power from the low field side by using 4 final mirrors each one injecting two convergent beams into the plasma. A fourth mirror is taken into account if two other gyrotrons should be added. The mirrors are vertically located at z=39cm, z=16 cm, z=−7cm and z=−30cm and R_1=433.6cm and R_2=426.3cm are the approximated radial positions of the pair of beams on each reflecting surfaces. The calculations of power deposition and ECCD are carried out by using a 3D quasi-optical code [2]; an input EC power of 5MW in a Gaussian beam is injected with a toroidal angle γ=20° by using different poloidal angles from the low field side at f=113GHz in the fundamental harmonic O-mode and f=170GHz at the second harmonic X mode. We model the JET-EP-like equilibrium with parameters characterizing a plasma at 3.3MA, R_{ax}=3.m, B_{ax}=3.4T (for absorption at 113GHz) and B_{ax}=2.6T (for 170GHz), Z_{eff}=2.5, $n_{e,ax}$=8 $10^{19}m^{-3}$, $T_{e,ax}$=10KeV. In Fig.1 the poloidal traces of the beams at 113GHz located at R1=433.6 cm are shown: the resonance zone at q=3/2 is also marked. The requirement for NTM stabilization to obtain the narrowest profile of EC deposition and of generated current selects the three lower vertical positions of the mirrors as the optimized paths of the radiation from the 6 gyrotrons as shown in Fig.2 ; in this figure the width of the ECCD channel at 1/e of the current density profile for f=113GHz at the two radial locations R_1 and R_2 is plotted vs the vertical mirror positions at q=3/2 and q=2. The beams at R_2 = 426.3cm show the best localization reconstructing their waist (=2.975cm) at 316.1cm with respect to the ones with waist (=2.871cm) at 325.8cm.

In Fig.3 the corresponding overall current density profiles, normalized to an input PEC power of 1MW, obtained by considering the 6 lower beams in the vertical direction are shown, peaked around q=3/2 and q=2. In Fig.4 the ray tracing for the beam, second harmonic X-mode, at f=170GHz from R_2=426.3cm and z=16cm is plotted with the resonant layer.

1.2 - ITER-FEAT

In ITER-FEAT a set-up of 8 gyrotrons per port are foreseen to operate at 1MW each. We consider 8 divergent beams at f=170GHz injected from the upper port into the plasma by 4 final mirrors located at R_1=630.92cm and z_1=478.25cm, R_2=644.18cm and z_2=460.3cm, R_3=657.44cm and z_3=460.35cm, R_4=670.71cm and z_3=451.41cm. The hardware constraints require to reflect two beams on a single final surface reconstructing the waist (minimum size of the beam) outside the plasma. Three launching schemes have been taken into account: the first one injects the radiation without focalization, the second with focalisation on a fixed mirror, placed between the waveguide and the launcher, and the third one with a focalising launcher. The ITER-FEAT equilibrium is given in [3] with resonant surfaces located at ρ=0.66 (q=3/2) and ρ=0.79 (q=2). The plasma with 15MA is characterized by R_{ax}=6.36.m, B_{ax}=5.16T, Z_{eff}=1.6, $n_{e,ax}$=10 $10^{19}m^{-3}$ and $T_{e,ax}$=28KeV. A fixed toroidal injection at γ=24° is considered in the designs. The best candidate to minimize the self-diffractive and refractive effects along the beam propagation is found to be the scheme 3 with waists (ranging from 2.16 and 2.25cm) closest to the plasma. In Fig.5 the poloidal traces of the beams of the scheme 3 are shown for the case resonant at q=3/2. In Fig.6 the overall current density profiles, normalised to 1MW, for the 3 launching schemes are plotted.

2. NTM STABILISATION

The NTM stabilization is a crucial task to avoid disruptions and confinement degradation due to the magnetic island growth. The control of these instabilities leads to reduce the island width below a threshold size, w_{thres}, where the NTM modes are suppressed. The localization of the ECCD inside the island can replace the bootstrap current reduced by the pressure flattening, thus avoiding that the mode size goes up to its saturated value, w_{sat}. In the present day tokamaks the typical values for wthres and wsat normalised to the minor radius are about between 0.01-0.02 and 0.08-0.15 respectively. We consider in JET-EP w_{thres}/a=0.012 and w_{sat}/a=0.09 (a=120cm) and in ITER-FEAT w_{thres}/a=0.02 and w_{sat}/a=0.13 (a=230cm). The stabilizing effects comes from both the RF term, which in the Rutherford's equation of the non linear island evolution [5] is proportional to δ_j^2/w^2 and the island rotation [4]. The width δ_j of the current density profile at 1/e is calculated 8.1cm (at q=3/2) and 9.5cm (at q=2) for JET-EP reference case and 10cm (q=3/2) and 7cm (q=2) for ITER-FEAT case.

In Fig.7 and in Fig.8 the reduction of the amplitude modes m=3, n=2 and m=2, n=1 are shown for JET-EP. An input PEC power of 5MW can be sufficient to stabilize separately both the modes. In Fig.9 and in Fig.10 same plots are given for ITER-FEAT for scheme 1 and 3.

CONCLUSIONS.

Optimised launching systems for JET-EP and ITER-FEAT devices allow to control separately NTM instabilities by injection of P_{EC}=5MW and P_{EC}=30MW, respectively. More power is required if both the modes have to be controlled in the same time.

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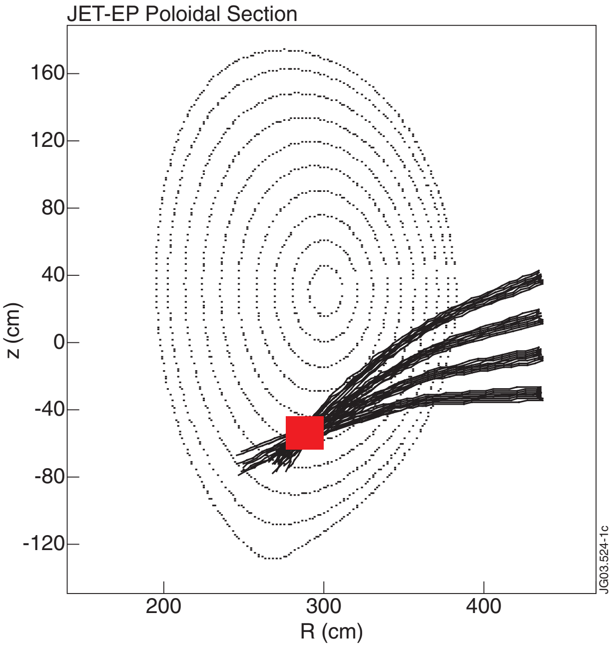

Figure 1: Poloidal traces of beams at 113GHz first harmonic O-mode located at R_1=433.6cm with EC absorption at q=3/2 (red square).

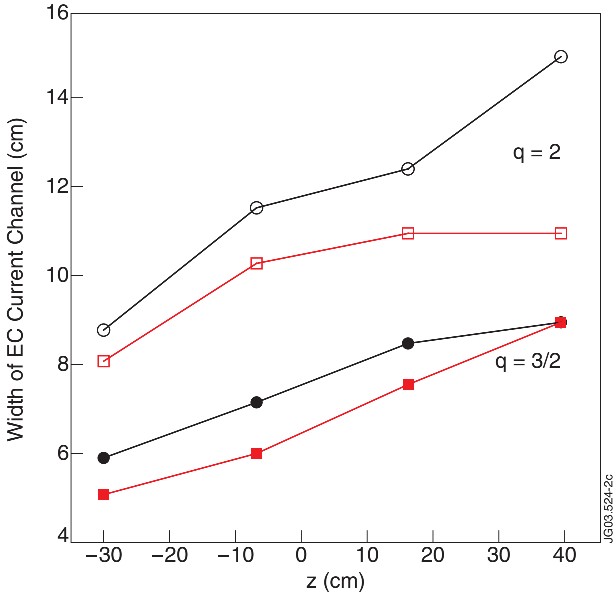

Figure 2: Width of the EC current channel vs the vertical coordinate of mirrors for two radial positions R_1=433.6cm (circles) and R_2=426.3cm (squares).

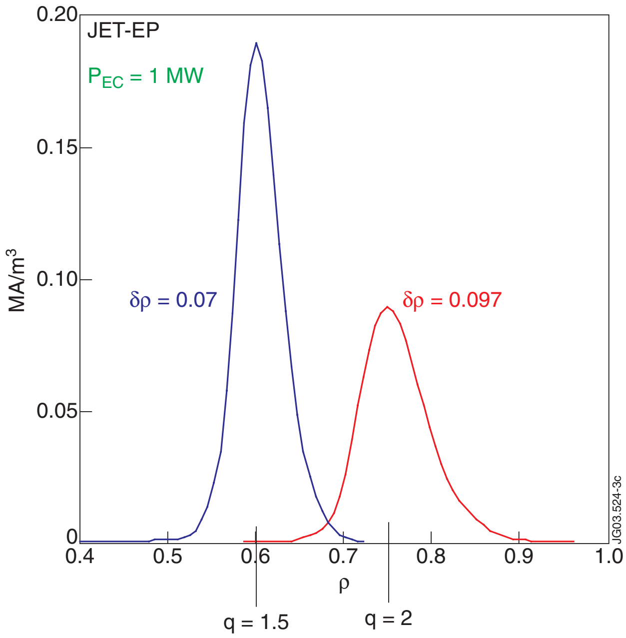

Figure 3: Overall current densiy profiles obtained by considering the 6 lower beams at f=113GHz.

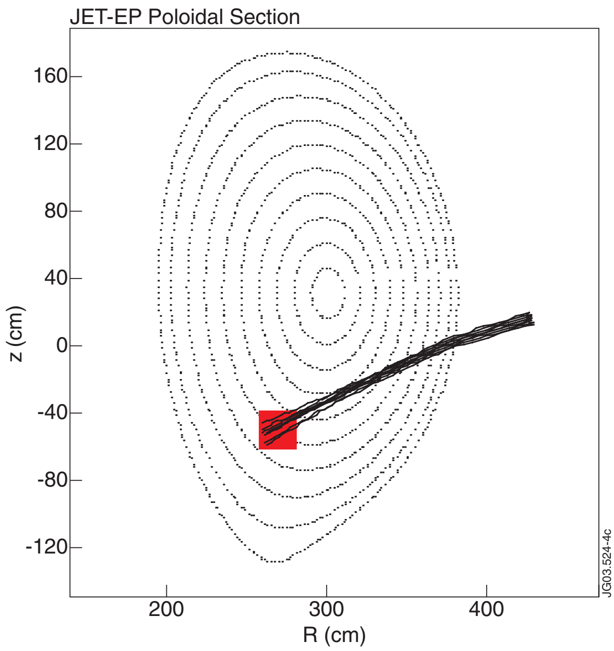

Figure 4: Polidal beam tracing at f=170GHz with absorption at q=3/2 (second harmonic X-mode).

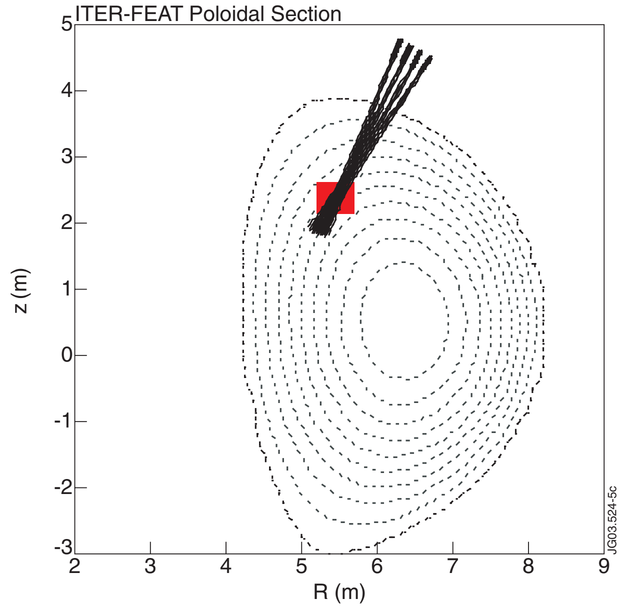

Figure 5: Poloidal beam tracing at f=170GHz with absorption zone at q=3/2 marked in red (square).

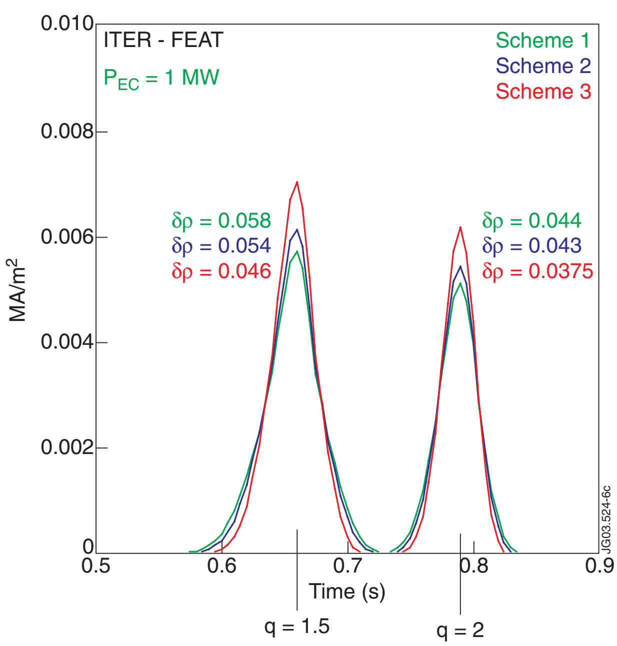

Figure 6: Overall current density for the three considered schemes normalised at 1MW input power.

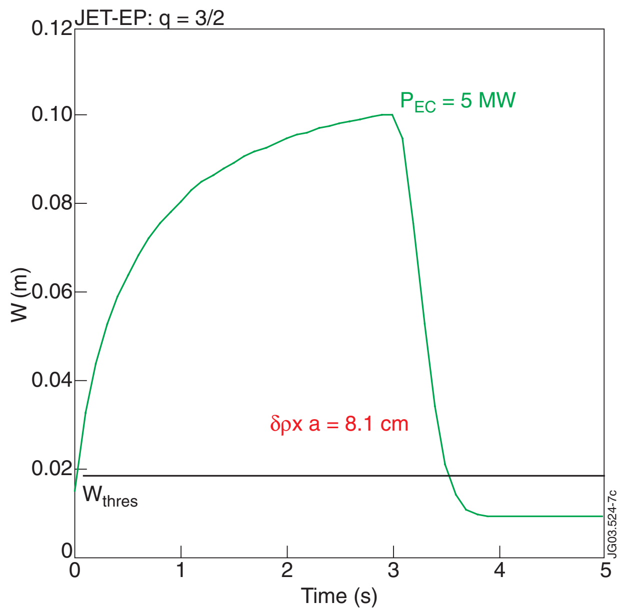

Figure 7: Amplitude evolution for m=3, n=2 mode in JET-EP with w_{thr}= 1.5cm and w_{sa} = 10cm.

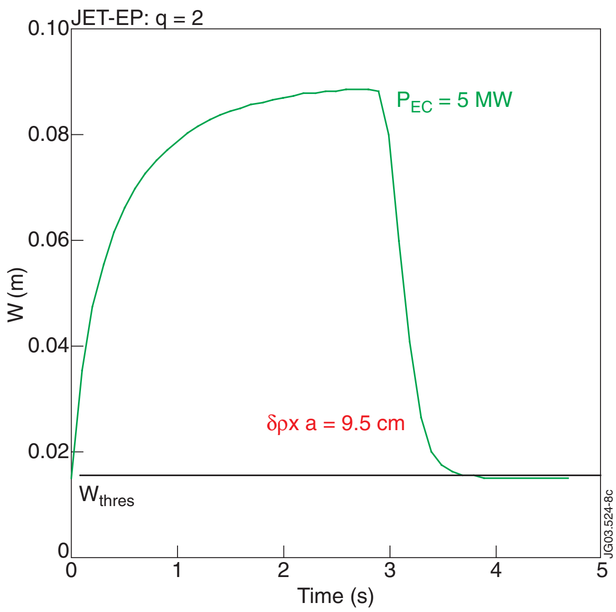

Figure 8: As Fig.7 for m=2, n=1 mode.

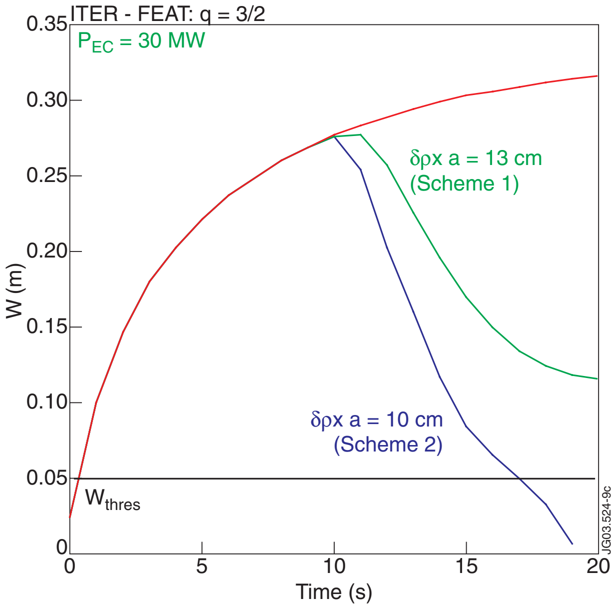

Figure 9: Island size evolution for m=3, n=2 mode in ITER-FEAT with w_{thre} = 5cm and w_{sa}= 30cm.

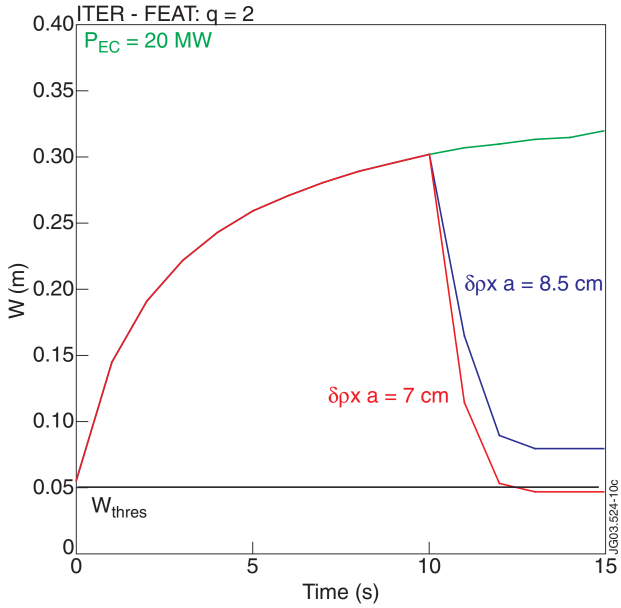

Figure 10: As Fig.9 for m=2, n=1 mode.