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Non-inductive current ramp up scenario and steady state regime optimization for Component Test Facility

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1. Introduction

One of the important steps on the way to a fusion reactor is the creation of a neutron source for testing the components. A few years ago the Component Test Facility (CTF) project based on the low aspect ratio tokamak concept, was proposed [1] and is being further developed. The problem of optimising the NB system for such a device is important as it is one of the main components of the project. Calculations for the optimization of the NB parameters were carried out in [2] are continued in this report. The result obtained with the free boundary equilibrium time evolution code DINA [3] is analyzed with the NUBEAM [4] code incorporated into the transport code ASTRA. Limitations on the coil current values (I_{PF}<6MA) and their positions, input NB power (50MW), fusion power (>35MW), transport (H-factor<1.3), geometry and TF rod current (~10.5MA) were formulated in [1]. The search for the optimized algorithm for plasma and beam parameters during the current ramp up scenario and steady state CTF regime is the main aim of this paper.

2. Model description

The free boundary equilibrium time evolution code DINA [3] is implemented for calculations of the current ramp up scenarios in CTF. Currents in the equatorial coils PF3&4 are controlled by the feed back condition on the position of the plasma magnetic axis. The currents in the other coils are prescribed and have been evolved during the plasma current ramp up evolution. The DINA code is used for current ramp up scenario calculations and for steady state, while NUBEAM code with ASTRA code are used for steady state calculations in order to test DINA results. The plasma current and the shape of the last closed magnetic surface are calculated based on the external magnetic field in the DINA code, while they are prescribed in the ASTRA transport calculations.

In both codes the plasma density profile, the averaged value of the plasma density and the tritium fraction are prescribed (50% of tritium in all reference regimes). Heat conductivity coefficients are taken the same for ion and electron heat fluxes and they are fitted to support the prescribed H-factor (H=1.3). The heat conductivity profile is varied in order to scan the peaking factor of the temperatures. The power of fusion alpha particles is taken to be fully absorbed by the main plasma. Plasma-plasma and beam-plasma contributions to the fusion power are taken into account. The neoclassical current conductivity is used in the poloidal flux equation. The NBI absorption is calculated taking into account the shine-through losses and secondary charge exchange losses on the cold neutrals. The bad orbit losses are taken into account in the NUBEAM code only which produces the difference in the results (less absorbed power in NUBEAM result). It is supposed to be the deuterium beam.

3. Current ramp up scenario optimization with the DINA code

As it was estimated [2] the NB of energy 135keV needs the plasma current above 1 MA for good capture. The initial low energy Neutral Beam (7MW/40keV) can be used to increase the plasma current from 0.5 to 1 MA.

The following criteria were taken in the search for the optimal scenario: **1.** The NB energy must not exceed 135keV and total power 50MW; **2.** The fusion power must be not less than 35MW, splitting on 28 MW in neutrons and 7MW in the alpha particles, **3.** The plasma stability to vertical and horizontal displacements, **4.** The absence of the sawtooth oscillations (q>1 over the plasma column). The main plasma parameters evolution during the current ramp up is shown in Fig.1. The possibility to satisfy the criteria pointed above is demonstrated in the calculations with the DINA code. The NB power is added by the portions in 5 and 10MW gradually enough in order to assimilate the NBCD and bootstrap current in the plasma: opposite Ohmic current becomes zero in each step. The plasma density increases fast to avoid shine-through losses of the high energy beam. The bootstrap current and NBCD contribution to the plasma current are equal in the steady state; as well the balance between these contributions corresponds to the balance between plasma density and input NB power during the scenario. The fusion power on the beam-plasma interaction increases faster than the thermal fusion contribution and in the steady state their contributions become equal.

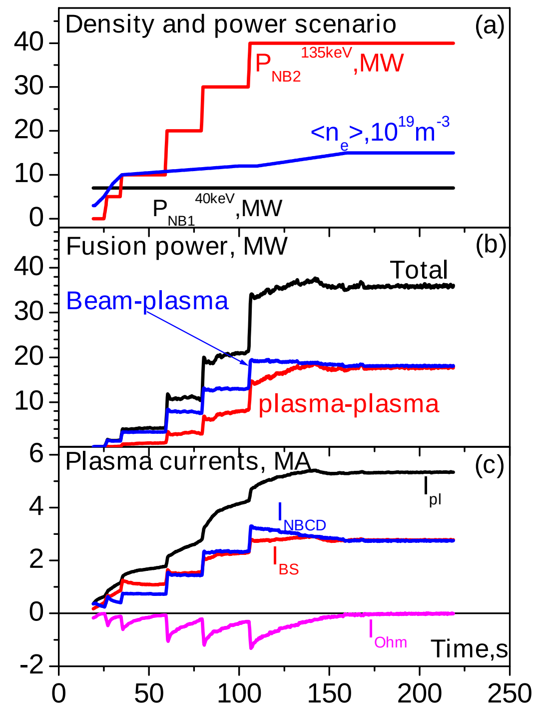

Fig.1 Current ramp up scenario plasma parameters: input NB power P_{NBI}, averaged plasma density <n> (a), fusion power (b), total plasma current I_{pl}, bootstrap current I_{BS}, NB current I_{NBCD}, and Ohmic current I_{Ohm} (c). Calculations with the DINA code

4. Steady-state regime for CTF

The calculations for steady-state CTF regime with the DINA code have shown the existence of maximal fusion power (optimal regime) in the beam energy and plasma density scan as it is shown in Fig.2. This allows us to choose the optimal plasma density and beam energy. The increase of the beam energy causes the deeper penetration of the beam and the higher internal inductance li which creates difficulties in the plasma column geometry control. Simultaneous plasma density increase helps to fix li but causes the reduction of the fusion power. The main plasma and beam parameters in the steady-state regime are shown in the Table.

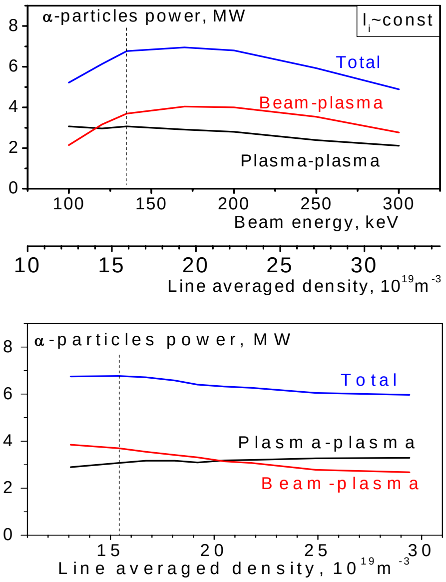

Fig.2 α-particle fusion power vs beam energy and plasma density. Calculations with the DINA code.

Table. Main plasma and beam parameters in the CTF steady state regime

	Previous projects		**Preliminary new calculations**	
Parameters	**Project [1]**	**CTF2006**	**DINA**	**ASTRA-NUBEAM***
R/a, m/m	**0.75/0.47**	**0.81/0.51**	**0.85/0.53**	**0.85/0.53**
Elongation	**2.5**	**2.5**	**2.31**	**2.31**
Triangularity	**0.4**	**0.4**	**0.33**	**0.33**
Plasma current, MA	**8**	**6.5**	**5.37**	**5.5 (I_{Ohmic}= - 0.6)**
Rod current / magnetic field	**10.5MA / 2.6T**	**10.5MA /2.6T**	**10.5MA / 2.47T**	**10.5MA / 2.47T**
Averaged density,	**$1.8\cdot10^{20}m^{-3}$**	**$1.8\cdot10^{20}m^{-3}$**	**$1.5\cdot10^{20}m^{-3}$**	**$1.5\cdot10^{20}m^{-3}$**
Averaged temperature	**Ti~Te~11keV**	**Ti=8keV Te=6.5keV**	**Ti=6.7keV Te=5.7keV**	**Ti=6.9keV Te=6.0keV**
NB Power/Energy	**50-60MW/150keV**	**40MW/135keV**	**7MW/40keV 40MW/135keV**	**7MW/40keV 40MW/135keV****
H-factor	**1.3**	**1.3**	**1.3**	**1.3**
Fusion power	**50MW**	**35MW**	**35MW, 55% on Beam-plasma**	**34MW 64% on Beam-plasma**
Neutron load	**~ 1.5 MW/m^2**	**~ 1 MW/m^2**	**~ 1 MW/m^2**	**~ 1 MW/m^2**

* optimized vertical NB launch angle α=30°
** only 35MW absorbed power

The project [1] was changed to CTF2006 in the direction of plasma current and input NB power decrease. The parameters optimization for steady state allows to obtain even less plasma current 5.37 MA with the less plasma density $1.5x10^{20}m^{-3}$ remaining the same beta normalized ~ 3.5. Approximately the half fusion power is going from the beam-plasma interaction which is effective for lower ion temperature and lower plasma density than the thermal fusion power.

5. Neutral Beam calculations with Monte Carlo code NUBEAM.

The steady state regimes calculations for NBI with the NUBEAM Monte Carlo code [4] incorporated into the ASTRA transport code were carried out in order to make a detail analysis of power balance from fusion reaction and NB absorption and of the NBCD source. The domination of the beam-target fusion power for the relatively low plasma density obtained in DINA code is confirmed. As for the thermal fusion power dependence on the plasma density the beam-target fusion power dependence also has a maximum as it is shown in Fig.3. The current drive efficiency strongly depends on the vertical beam angle and has a maximum on 30 degrees (see Fig.4). For this angle the NBCD and the bootstrap current total value in the reference regime exceeds the plasma current by 0.6MA as it is shown in the last column of the Table.

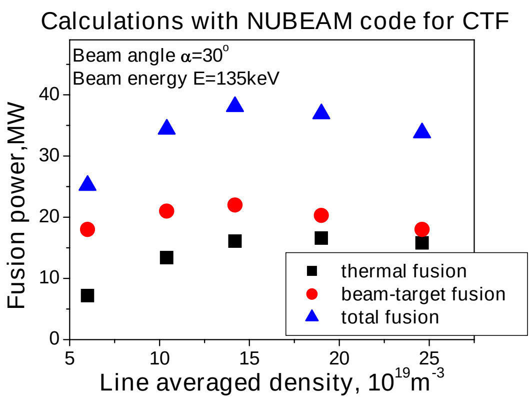

Fig.3 Fusion power vs plasma density. NUBEAM results

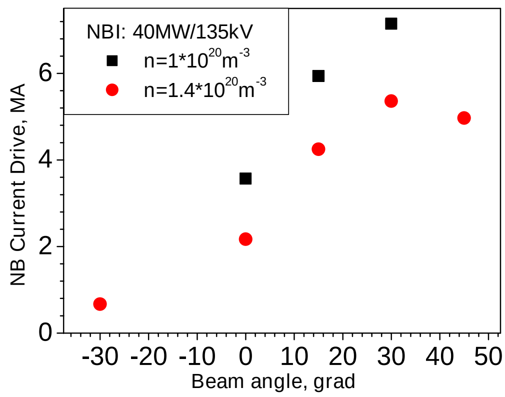

Fig.4 Current driven by NB vs NB vertical angle. NUBEAM results

6. Conclusions

The possibility of a consistent current ramp up scenario was demonstrated with the free boundary equilibrium evolution DINA code. The CTF steady state regime was analyzed with two different codes. The algorithm of the beam energy and plasma density optimization for fusion power is obtained. The beam-target plasma reaction makes from 55% to 64% of the total fusion power enhancing the thermal plasma-plasma fusion contribution. The NB vertical angle is found to be the critical parameter for current drive efficiency.

Reference

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