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Single Null Negative Triangularity Tokamak for Power Handling

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Critical Issue in H-mode in DEMO:

The H-mode is a standard operation mode in ITER. But its applicability to DEMO is still not sure [1]. Recent scaling law of SOL heat width in H-mode [2] as well as large predicted ELM energy loss [3] cast a question to the feasibility of H-mode for DEMO from the viewpoint of power handling [1]. In order to reduce the heat load on the divertor plates, the detached divertor plasma with the large remote radiative cooling may be inevitable. For this sake, a high SOL density is desirable. If the SOL density is necessarily high, the pedestal density will become enough high and the pedestal temperature will be limited low by the MHD stability. This lower pedestal temperature might cause the degradation of H-mode energy confinement performance as generally observed in the H-mode experiments towards high density near the Greenwald density limit. To avoid the above pessimistic scenario, it might be important to study some alternative scenarios for DEMO. Fortunately TCV "negative triangularity" experiments have shown encouraging results in the ELM characteristics and the confinement performance [4].

Single Null NTT:

Power and particle control in fusion reactor is quite a challenge and we have studied the negative triangularity tokamak (NTT) as an innovative concept to reduce the transient ELM heat load and the quasi steady-state heat load in both double- and single-null configurations [5, 6]. Ideal MHD stabilities of NTT configurations have been studied by S. Medvedev et al. for both double-null and single-null (SN) [5, 6] showing that a reactor-relevant normalized beta $\beta_N > 3$ can be stable even when the wall stabilization is nullified.

Because the SN configuration is suitable for the DEMO design from the viewpoint of engineering construction, maintenance, and operational control, we here concentrate on the SN. Figure 1 shows a proposed SN-NTT configuration. The major plasma parameters are $R_p = 9$ m, $a_p = 3$ m, $I_p = 21$ MA, $B_t = 5.86$ T, $\varkappa_{95} \approx 1.7$ and $q_{95} \approx 3.0$. The lower triangularity is set as $\delta_u = -0.9$, while the upper triangularity is controlled flexibly $-0.4 < \delta_u < 0$ by adopting rectangular-shaped TF coils. The attainable beta limit is $\beta_N = 3.56$ with the wall stabilization and $\beta_N = 3.14$ for the no-wall case. The vertical stability is assured under a reasonable control system. As for the ELM characteristics, it is found by the EPED-CH study that pedestal pressure can be reduced by a factor of 4 so that energy loss is much more reduced even if ELM occurs [7].

The wetted area on the divertor plates becomes wider in proportion to the larger major radius at the divertor strike points due to the NT configuration. In addition to the major-radius effect, the "Flux Tune Expansion (FTE)" [8] is adopted to further reduce the heat load on the divertor plate. Pair of PF coils called the FTE coils are settled inside the TF coil not far from the divertor strike point, and the flux tube is expanded by a factor 2.2-2.6 with a coil current $I_{FTE} \approx 3$ MA much smaller than the divertor coil current ~20 MA.

The reliability of the proposed NTT DEMO has been studied using SYS-code. The fusion power of 3 GW is deliverable only at $\beta_N = 2.1$ which is much smaller than the no-wall beta limit $\beta_N = 3.14$. Therefore this reactor may be operable stably against the serious MHD activities. The CD power for the steady state operation is estimated as 175 MW, i.e. Q = 17. The OH coil can be installed for the current ramp-up and for an AC operation with a period of a few hours. A required HH factor is relatively modest $H_H = 1.12$, which may be achievable by a combination of the sawtooth-free operation and the TEM stabilization through negative triangularity.

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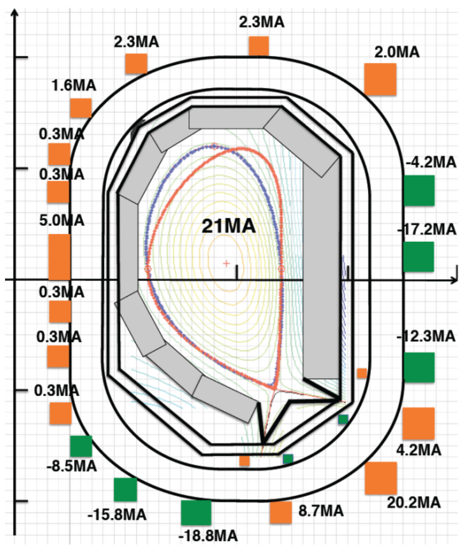

Figure 2 Cross sectional view of SN-NTT [6].