*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-5.170 (2004)*

Dual feedback controlled high performance Ar seeded ELMy H-Mode discharges in JET including trace tritium experiments

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Summary

A dual feedback control system was successfully implemented on JET to control high performing Ar seeded ELMy H-mode discharges. Controlled parameters are the confinement enhancement factor H98(y,2) and the total (or partial) radiated power fraction $\gamma = P_{rad}/P_{tot}$. Control parameters are the Deuterium and impurity (Ar) fuelling rates. This scheme was applied to trace T discharges and lead to discharges exhibiting the following performance: H98(y,2) ≈ 1, $n/n_{GW} \approx 1$, $\beta_n \approx 2$ and $\gamma \approx 0.65$. The total radiated power was not significantly increased as compared to the unseeded reference case due to large intrinsic radiation inherent to the used configuration (HT3 with the MkIIGB-SRP divertor) and the "exchange" between intrinsic and extrinsic radiation. The time of penetration of T is higher in the Ar seeded case but this is essentially explained by the higher density reached.

Dual feedback control: motivation and principle

The reference scenario for ITER is operation in ELMy H-mode with $n/n_{GW} = 0.85$, $\beta_n = 1.8$ and H98(y,2) = 1. These values are routinely achieved in JET in Ar seeded ELMy H-mode discharges [1,2,4]. The seeding of low Z impurities aims at modifying the

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[*] *See annex of J. Pamela et al, "Overview of JET Results", Fusion Energy 2002 (Proc. 19th Int. Conf. Lyon, 2002), IAEA, Vienna (2003).*

radiation pattern of the plasma allowing a better radiated power distribution and reducing the divertor target load.

Previous experiments demonstrated the potential benefits of Ar seeding in terms of integrated scenario [1,2]. A major concern in this scenario is the stationarity of the discharge: main plasma parameters are indeed very sensitive not only to the Ar seeding rate but also to the D_2 fuelling rate. Furthermore both are not acting independently. Hence the difficulty to predict the necessary main and impurity gas rates and the necessity to develop a feedback system to control these.

A dual feedback system was developed in order to control both the values of H98(y,2) and $\gamma = P_{rad}/P_{tot}$. The D_2 puffing rate and the Ar seeding rate are used as actuators. Confinement and radiation were chosen as controlled parameters since they were the best correlated quantities with the actuators and that it preserves the confinement quality of the discharge. Furthermore it allows to maximise the D_2 fuelling rate for a given confinement and radiation. The feedback scheme uses a 2 by 2 control matrix, which is established from open-loop experiments with step requests for the actuators and is valid around the chosen operational point. The plasma model – essentially described by this matrix - is then tested on several discharges from the existing database. If the plasma model is satisfactory it is implemented in the feedback loop (Fig. 1) in order to test the stability of the scheme and optimize the PIDs. Once confident, the feedback loop can be closed and used in real situation. This scheme is only valid around the operating point for which the control matrix has been determined.

Application to trace T discharges

Both tritium (T) beam blips and T gas puffs have been applied in these discharges. Fig. 2 shows an example of two discharges with a T puff: one with Ar seeding and a reference discharge without Ar seeding. The T is puffed at 20 s. In the case of the Ar seeded discharge, the dual feedback on H98(y,2) and γ was used. In the reference discharge, a single feedback on H98(y,2) with the D_2 fuelling rate as actuator was used. Both discharges are under same machine and operational conditions. Performance of the Ar seeded discharge is as follows: H98(y,2) $\approx$ 1, $n/n_{GW} \approx 1$, $\beta_n \approx 2$ and $P_{rad}/P_{tot} \approx 0.65$. The neutron yield is lower for the Ar seeded discharge but this is essentially due to the lower electron temperature resulting from the higher density reached in this discharge. Note that discharges with similar density and confinement performance can also be achieved without Ar seeding [5]. There is no increase in Z_{eff}.

Interpretative transport analysis using the TRANSP code shows a reduction of ion thermal and particle transport achieved in the Ar seeded discharge as compared to the reference case [6]. The plasma density increases by 20% with the same D source when Ar is injected and the χ_{eff} value reduces by a factor 2 in the gradient zone due to reduced thermal ion diffusivity.

As can be seen from Fig. 2 the total radiated power fraction is not significantly larger with the Ar seeding. This is due to the high intrinsic radiation inherent to the HT3 configuration used with the MkIIGB-SRP divertor (in opposition to the EHT configuration used with the MkIIGB divertor [1]). In this case the extrinsic radiation partly replaces the intrinsic radiation and the total radiation is not changed much. This leads to the choice of another control parameter in subsequent experiments: the partial radiated power fraction $\gamma_u = P_{rad,u}/P_{tot}$, where $P_{rad,u}$ is an estimate of the radiated power in the main chamber, i.e. not taking into account X-point nor divertor radiation. This feedback scheme was successfully tested with steps in the requested values around the operating point.

T penetration is monitored in the discharges with T puffs by observing the delays, rise-times and decays of each channel of the 19-channel neutron camera. This camera is equipped with two sets of detectors (Ne213 and Bicron) detecting the 14 MeV D-T neutron emission, which showed the same characteristics for the penetration of T puff into the plasma. Fig. 3a displays the normalized channel intensity for 5 channels of the Bicron detector (channel 1 being the most outward channel) for the two discharges of Fig. 2. The maximum of the neutron emissivity happens later for the more central chords in the Ar seeded case reflecting a longer time of penetration of the T. Fig. 3b displays the normalized channel intensities for the Ar seeded discharge and for a discharge without Ar seeding reaching the same density as the Ar seeded one but at different machine and operating conditions (B_t = 2.25T instead of 2.7T). Time of penetration is similar in this case.

Predictive modelling of these three discharges using the JETTO-SANCO code shows that anomalous contribution to T transport is reduced in high density discharges so that overall T particle diffusivity and pinch velocity approach the neo-classical level. Plasmas with lower density require significant contribution from anomalous transport to ensure observed faster penetration of tritium particles towards the plasma centre [7].

Interpretative transport analysis using the TRANSP code also leads to the conclusion that the T pinch is close to the neo-classical value at high density whereas it becomes strongly anomalous at low density [6].

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