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Recent Results from W7-AS with the new radial NBI injector

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Abstract:

During the last two years, a new radial neutral beam injector with an almost perpendicular injection angle has been built and commissioned on W7-AS. The objective of the project is to study both the interaction of perpendicular injection and the generation of a radial electric field in the plasma. In this paper recent results will be presented from W7-AS with NBI operation of the new radial injector.

Introduction:

The radial injector is equipped with two new RF-sources for a total power of 550kW. It is, however, not a "heating injector". The injection angle is 15° in the duct. Depending on the W7-AS magnetic field configuration the fast ions from the radial injector cannot perform a helical circulation and are, therefore, quickly lost due to particle drift. This fast ion loss results in a change of the radial electric field, E_r. This radial electric field is very important for the neoclassical confinement of the ions in a stellarator, as known from the W7-A stellarator [1].

The objective of the radial injector is to improve neoclassical confinement with an additional E-field driven by the injector's fast ion loss. For the successful operation of the radial injector, it's necessary to have: the W7-AS B-field ripple for fast ion loss, a minimum density of about $n_e(0)=1\ 10^{20}m^{-3}$ to minimize shinethrough, and a sufficient high T_e to have a low collisionality, for the action of the E-field on the plasma ions to become effective.

The fast ion loss is measured with a Fast Ion Loss detector located at a position next to the radial injector. The electric field is measured by passive B IV spectroscopy; the ion temperature is measured by both passive BIV spectroscopy and by neutral particle analysis.

Results and discussion:

The new radial injector has been in operation since November 2001. The first experiments with the radial injector operating in hydrogen were performed with different magnetic field configurations and background heating scenarios.

Fig. 1 shows one example for two similar discharges: one without the radial injector and the second one with radial injection of hydrogen between 410 and 610 ms. The stored energy for the second case is about 1 kJ higher than without radial injection. Even after the radial injector is switched off, it remains on a slightly higher level. After 400 ms there is in both discharges a transition towards optimized confinement. But as this occurs without the radial injector too, the perpendicular NBI may not be the cause for this transition.

For the evaluation it is necessary to take into account that not all the fast ions created by the radial injector are lost. A small amount stays in the plasma and the result is additional heating power. Fig. 1b) shows the power to the plasma. The total power of the radial injector is 580 kW. The shinethrough is 33% or 191 kW and will not be available for the generation of an electric field. A small percentage of 13% of 75 kW is ionized and not lost by the fast ion loss. So the total heating power in the radial injector phase is 75 kW higher than without the radial injector. The remaining 54 % perform a fast ion loss and the result is a change of E_r.

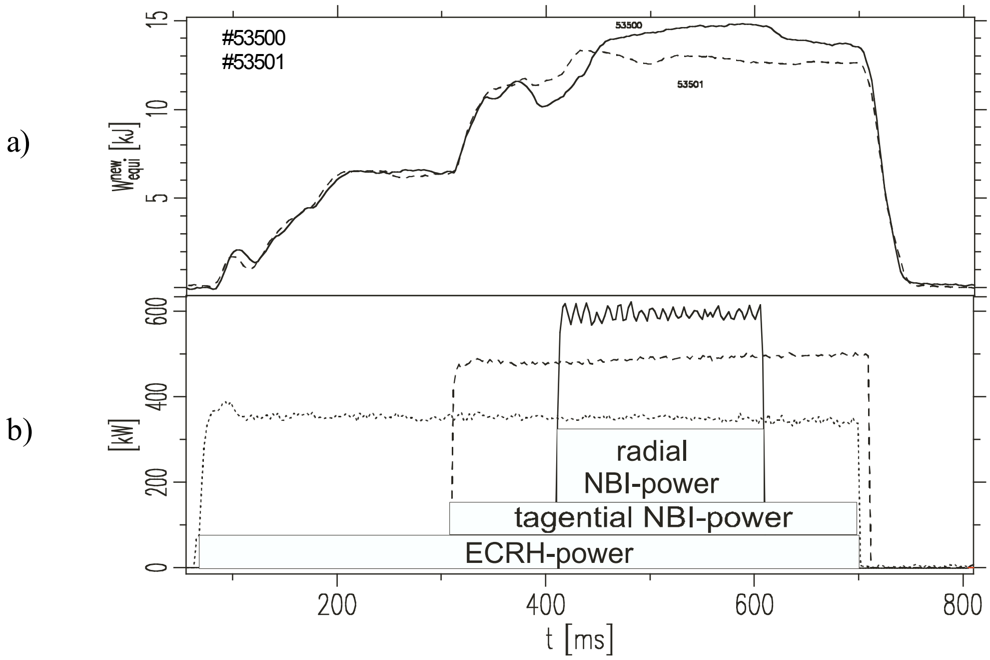

Fig. 1: a) Stored energy for two similar discharges with radial injection of hydrogen (solid line) and without radial injection (dashed line). b) Power to the plasma for the two discharges above. The background plasma is heated by one 140 GHz gyrotron and one tangential NBI source. Between 410ms and 610ms the radial injector is switched on for one discharge only. About 33% of the radial NBI-power is lost because of the shinethrough, 13% stay in the plasma resulting in an additional heating power of about 75 kW and 54% of the power is lost by the fast ion loss. This fast ion loss results in a change of the radial electric field, E_r. ($B=2.5T$, $n_e(0)=0.8\ 10^{20}m^{-3}$, $T_e(0)=1keV$)

The slightly higher heating power has to be taken into account in the evaluation. The rise of the stored energy in the radial injector phase ΔW can be estimated as the additional heating power ΔP multiplied by the energy confinement time τ_e. If the overall confinement of the plasma is improved by the radial electric field E_r, than τ_e and thus ΔW should be larger than expected from this simple consideration above. For the example of Fig. 1 the rise of the stored energy ΔW is 1 kJ. With the energy confinement time taken from the W7-95 scaling the expected ΔW because of the additional heating power is 0.9 KJ. With respect to the errors bars of this simple consideration the rise of the stored energy ΔW is not an effect of the generation of a radial electric field. It is only determined by the small heating power of the radial injector. Nevertheless a change of the radial electric field E_r and of the ion temperature T_i is observed during the radial injector phase (see below). For hydrogen injection the measured ion temperature profile is getting broader. This is confirmed by the independent measurement of T_i with the W7-AS charge exchange flux diagnostic.

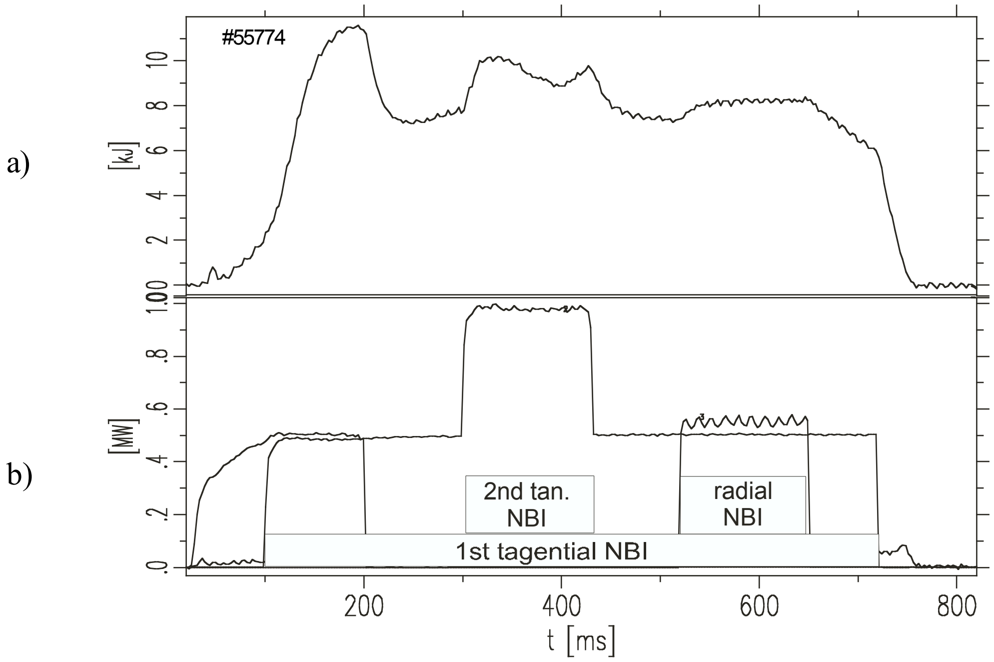

Fig. 2: Radial injection with deuterium into hydrogen plasma. a) Stored energy. b) Power to the plasma. The background plasma is heated by one tangential NBI source. Between 300ms and 420ms a 2^{nd} tangential NBI source and between 520ms and 650ms the radial injector is switched on. 5% of the radial NBI-power is lost because of the shinethrough, 10% stay in the plasma resulting in an additional heating power of about 48 kW and 85% of the power is lost by the fast ion loss. (B=2.5T, $n_e(0)=0.8\ 10^{20}m^{-3}$, $T_e(0)=600eV$)

The same evaluation can be made for the case of deuterium injection with the radial injector (fig. 2). Because of the smaller beam velocity the shinethrough of the deuterium beam is smaller. On the other hand the fast ion loss is even larger. The experimental change of the stored energy ΔW during the radial injector phase is 1 kJ. The theoretical rise according to the simple evaluation above is only 0.6 kJ. Although it is not a big effect in the stored energy, the difference could be accounted to the radial electric field. However, the heating efficiency of the radial beam is not independent on E_r. The heating power is getting larger with an electric field and this is not considered in the simple estimation above. A more detailed evaluation has to be made in the future, whether this small rise in the stored energy is really an improvement in the global confinement due to E_r or it is simply an effect of the additional heating power.

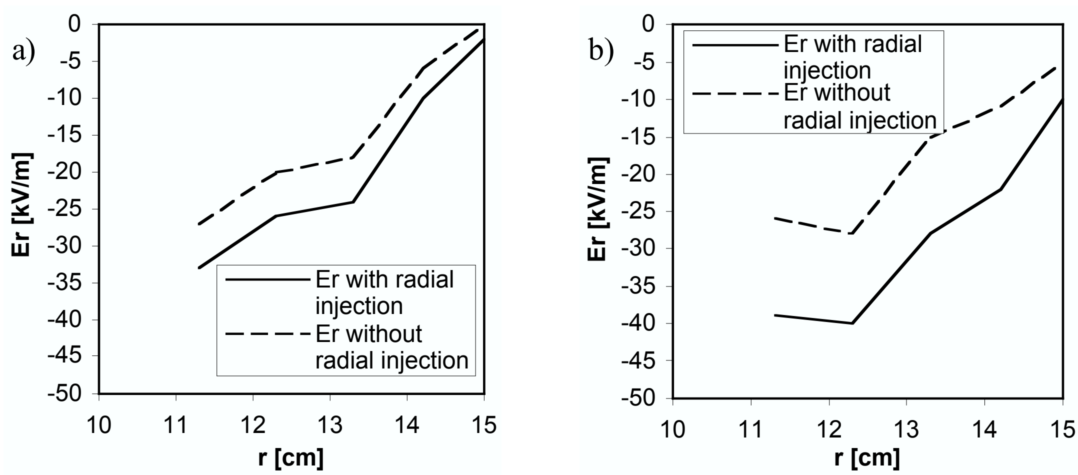

Fig. 3: The radial electric field E_r at the plasma edge without radial injection and at the end of the radial injection phase. a) The radial injector is running with hydrogen. b) The radial injector is operating with deuterium.

In fact the change of E_r during the radial injector phase is significantly larger for the deuterium case. Fig. 3a) shows the radial electric field E_r for the same shot with hydrogen injection as shown in fig. 1. Fig. 3b) corresponds to the deuterium discharge of fig. 2.

Conclusion:

The central point of the investigation was whether the radial injector could enhance the generation of a radial electric field and thereby help to trigger transitions towards optimized confinement or H-mode. The results have so far not shown any significant effect on the global plasma parameters by the use of the radial injector with hydrogen. For deuterium injection, which reduces shinethrough and increases the fast ion loss, a small increase of the stored energy could be related to the generation of a radial electric field by the perpendicular injector. The further evaluation will show whether it's an improvement of the global confinement or an enhancement of the heating efficiency of the radial injector due to E_r.

References:

[1] H. Wobig, H. Maaßberg, H. Renner, W7-A Team, ECRH Group, NI Group, *Plasma Confinement in the W7-A Stellarator*, Plasma Phys. and Contr. Nuclear Fusion Research, Vol. 2, 11th conf. proceedings, Kyoto 13th-20th Nov 1986, Nucl. Fusion Supplement, 369, (1987)