Validation of halo current model with DINA code against ASDEX Upgrade disruption shots

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Introduction. Due to electron temperature drop after thermal quench during a major disruption in tokamak plasma the plasma current decays to zero. Together with this the plasma region with closed magnetic surfaces decays to zero because of vertical movement of the elongated plasma. Both decays generate the electric fields which drive a current, named “halo”, flowing around the core plasma along the helical field lines outside of the last closed magnetic surface.

To predict a halo current evolution during disruption in tokamak plasma the model for the halo region width was included in the DINA code [1], which is based on conservation of toroidal magnetic flux within the plasma cross-section. DINA halo model is being used for disruption modeling in ITER plasma [2] and validated against an experimental database in MAST [3] and JT-60U [4] of disruptions. That validation was mainly focused on comparison of the modeled time evolution of *total* halo current with the measurement data.

This paper concentrates on the comparison between the DINA modeling results and experimental data in AUG, which have the detailed measurements of the poloidal halo current profile evolution during disruption. Downward VDE disruptive shots #24999 and 25000 in AUG plasma created by the intentional kick of the vertical control system are being considered here.

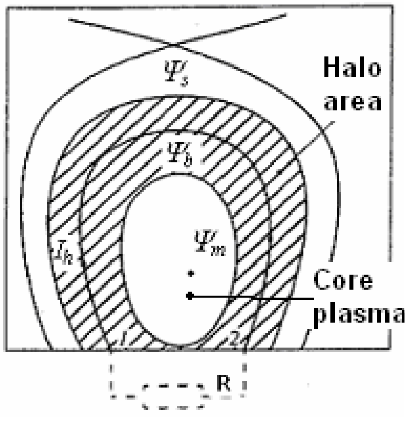


Fig. 1. Limited core plasma together with halo area

Physical model of halo area expansion, see [5]. The toroidal component of halo current during a disruption results from a high toroidal electric field, because the plasma current terminates after a thermal quench. The poloidal halo current component $I_{h\ pol}$ is a result of toroidal magnetic flux, which changes inside the last closed magnetic plasma surface. Such a change is becoming particularly significant during VDE in limiter phase when a part of toroidal flux shrinks by limiter together with plasma as shown in Fig. 1. Inside of core plasma the poloidal flux Ψ changes within poloidal flux in plasma axis Ψ_m and plasma boundary Ψ_b.

Inside of the halo area the value of Ψ decreases from Ψ_b up to Ψ_s. We define the halo area width w as $w = \frac{\Psi_b - \Psi_s}{\Psi_m - \Psi_b}$ [5]. In Fig. 1, R denotes the electrical resistance of the surrounding conducted structure between the points 1 and 2. The DINA code model of halo area expansion during a plasma disruption is based on the assumption of approximate conservation of the toroidal magnetic flux inside the poloidal surface S combining the core plasma and the halo region (see Fig. 1). Because the toroidal magnetic flux is proportional to S, the scaling of the halo width in the DINA code is as following:

$$\frac{S_0}{S(t,w)}\left(C + \frac{I_p(t,w)}{I_{p0}}\right)\frac{1}{C+1} = 1 \cdot \tag{1}$$

Eq.(1) has to be valid at each time moment t during the plasma disruption. Here S_0 and I_{p0} are the poloidal surface and the plasma current values before the thermal quench beginning, $S(t,w)$ and $I_p(t,w)$ are the mentioned parameters at the current time moment t after thermal quench. The S value is the total core plasma and halo area surface. That is before the halo current generation the value of w is supposed to be equal 0. The term $\left(C + \frac{I_p(t,w)}{I_{p0}}\right)\frac{1}{C+1}$ in expression (1) is taking into account the possible decrease of toroidal flux, which is assumed to be proportional to I_p. Here C is a fitting coefficient, which can be different for various tokamaks. In [4] the DINA fitting analysis has shown that scaling (1) provides the acceptable agreement with experimental data from JT-60U for $C \geq 2$. In the present paper, scaling (1) is being briefly validated against the measured poloidal current in AUG, while using the DINA fitting model. Both experimental and DINA results are defined from the expression, which includes the halo components flowing through the tiles in the lower outer (DUA), middle (DUM) and inner (DUI) divertor plates, as shown in Fig.2 [6]:

$$I_{halo\ pol} = [(I_{DUIoo} + I_{DUIou} + I_{DU\,\mathrm{Im}} + I_{DUIu} + I_{DUMi} + I_{DUMoi}) - (I_{DUMoa} + I_{DUMa} + I_{DUAu} + I_{DUAm} + I_{DUAo} + I_{DUAxo})] * 0.5.$$

In result of DINA predictive analysis the evaluation of electron temperature in halo area in disruptive AUG plasma is obtained.

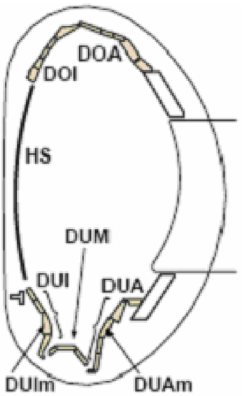
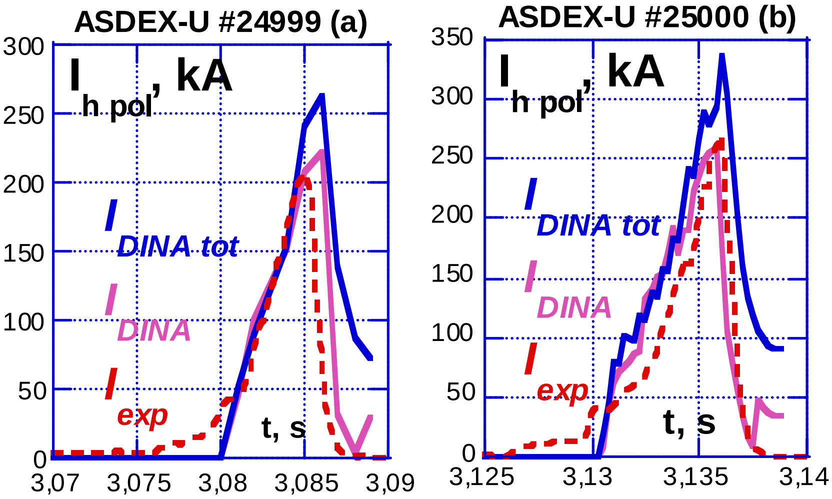


Fig. 2 Halo current measurements through tiles in ASDEX Upgrade

Comparing DINA fitting analysis with experimental ASDEX Upgrade data. In the DINA fitting model, the plasma magnetic poloidal fluxes Ψ_m, Ψ_b, Ψ_s (see Fig.1) are obtained as a result of "fitting" the calculated values in the flux loops and magnetic probes to the experimentally measured quantities with use of expression (1) as described in [7]. Fig. 3 presents the time traces of $I_{h\ pol}$ in reconstructed and diagnostic halo regions compared with shots 24999 and 25000.



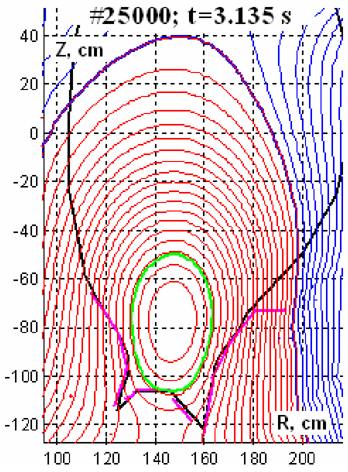


Fig. 3 Fitted poloidal halo currents within reconstructed halo area and within diagnostic area in comparison with experimental halo current data in 24999 (a) and 25000 (b) disruption AUG shots

Fig. 4 Example of reconstructed plasma equilibrium in shot 25000 at the time moment of $(I_{h\ pol})_{\max}$

One can see that the peak value of experimental poloidal component of the halo current is reproduced with an accuracy of about 10 %. Besides the modeling results show that outside of the diagnostic area about 20 % of the total halo current is expected to flow, because the reconstructed area is *wider* than the diagnostic one - see Fig. 4, where the halo area is represented by red color outside of the green line, while the last-closed magnetic surface and diagnostic tiles are drawn by magenta color.

DINA predictive analysis results of AUG data. Free plasma boundary DINA predictive analysis has been carried out to evaluate the level of electron temperature in the halo area, T_e^{halo}, in both #24999 and #25000. Such a level has been selected to obtain the best correspondence between the simulated and the measured poloidal current distributions in the halo area. Behaviour of the averaged plasma electron temperature during the current quench is adjusted to reproduce the experimental plasma current time evolution during the current quench. Presented results include the $\alpha = T_e^{core}/T_e^{halo} \geq 1$ coefficient,

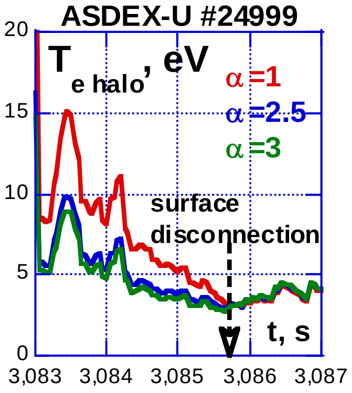


Fig. 5 Predictive time traces of T_e in halo area depending on α value in 24999 shot

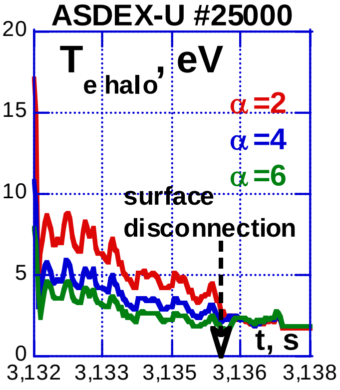


Fig. 6 Predictive time traces of T_e in halo area depending on α value in 25000 shot

while denote the relation between the values of T_e in the core and halo areas. The value of Z_{eff} is specified to be Z_{eff}=2 through all plasma area. In Figs. 5 and 6, the predictive time traces of T_e in the halo area, depending on α, for shots 24999 and 25000 are presented. Figs. 7 and 8 demonstrate the results of predictive $I_{h\ pol}$ in 24999 shot for C=1 (*narrow* halo area) and C=6 (*wide* halo area). Predictive halo current distributions across two tiles DUIou and DUMa in 25000 shot are shown in Figs. 9 and 10. In Figs. 7-10 the experimental data behavior is presented. One can see that the maximum of poloidal halo current *decreases* with *increasing* of halo area width. Besides, there is a strong dependence of halo current behavior on the level of T_e in halo area. A reasonable correspondence between the predictive and experimental halo currents is obtained for C = 1, with the value of α= 2.5 in #24999 and α= 4 in #25000.

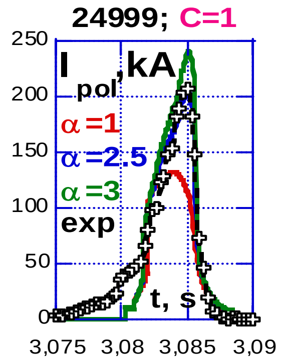


Fig. 7 Time traces of predictive $I_{h\ pol}$ during 24999 shot for C=1

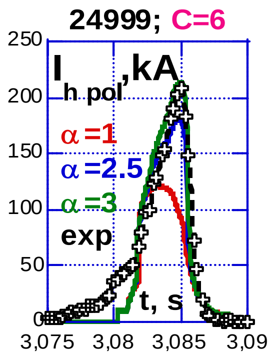


Fig. 8 Time traces of predictive $I_{h\ pol}$ during 24999 shot for C=6

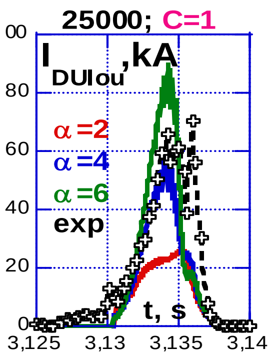


Fig. 9 Time traces of predictive I_h in DUIou tile during 25000 shot

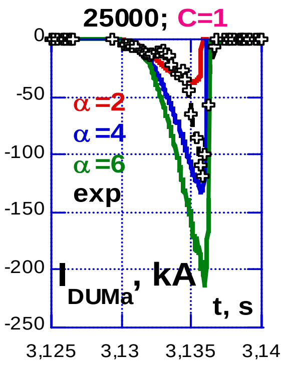


Fig. 10 Time traces of predictive I_h in DUMa tile during 25000 shot

Conclusion. Resulting agreement between experimental and modeled halo current behaviour in ASDEX-U disruptive plasma, performed with both fitting and predictive modes of DINA code and proposed empirical relation for the halo region width is quite encouraging. The peak value of halo current is reproduced within an accuracy of 15-20%. Level of T_e in halo area is 3÷15 eV in shot 24999 and 2÷8 eV in shot 25000. The value of electron temperature in the halo area is expected to be in 2÷3 times smaller than the electron temperature in plasma core.

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