Real-time diamagnetic flux measurements on ASDEX Upgrade

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Introduction

Real-time diamagnetic flux measurements are now available on ASDEX Upgrade. The diamagnetic flux is the difference in total toroidal flux with plasma and without plasma [1]. From the diamagnetic flux measurement, the global values of the plasma internal inductance, diamagnetic plasma energy and poloidal beta can be calculated [2]. In contrast to the majority of diamagnetic flux measurements on other tokamaks, no analog summation of signals is necessary for measuring the change in toroidal flux or for removing contributions arising from unwanted coupling to the plasma and poloidal field coil currents. To achieve the highest possible sensitivity, the diamagnetic measurement and compensation coil integrators are triggered shortly before plasma initiation when the toroidal field coil current is close to its maximum. In this way the integration time can be chosen to measure only the small changes in flux due to the presence of plasma. Two identical plasma discharges with positive and negative magnetic field have shown that the alignment error with respect to the plasma current is negligible. The measured diamagnetic flux is compared to that predicted by TRANSP simulations. The poloidal beta inferred from the diamagnetic flux measurement is compared to the values calculated from magnetic equilibrium reconstruction codes. The diamagnetic flux measurement and TRANSP simulation can be used together to estimate the coupled power in discharges with dominant ion cyclotron resonance heating.

Diamagnetic flux loop

A schematic diagram of the external diamagnetic loop on ASDEX Upgrade is shown in Fig.1. The measurement loop and the compensation loop are indicated. Two sets of internal and three sets of external diamagnetic loops are installed on ASDEX Upgrade [3]. The external measurement loop is 2 windings in the poloidal direction around the outside of the vacuum vessel. The compensation loop is used to measure the vacuum toroidal field and has 4 separately wound coils aligned in a guide tube mounted in a 10 mm deep machined groove support structure on the outside of the vacuum vessel. The measurement loop is also wound on the same support structure and this ensures the measurement and compensation loops cannot move independently in the toroidal magnetic field. For a test discharge with individual currents in each of the poloidal

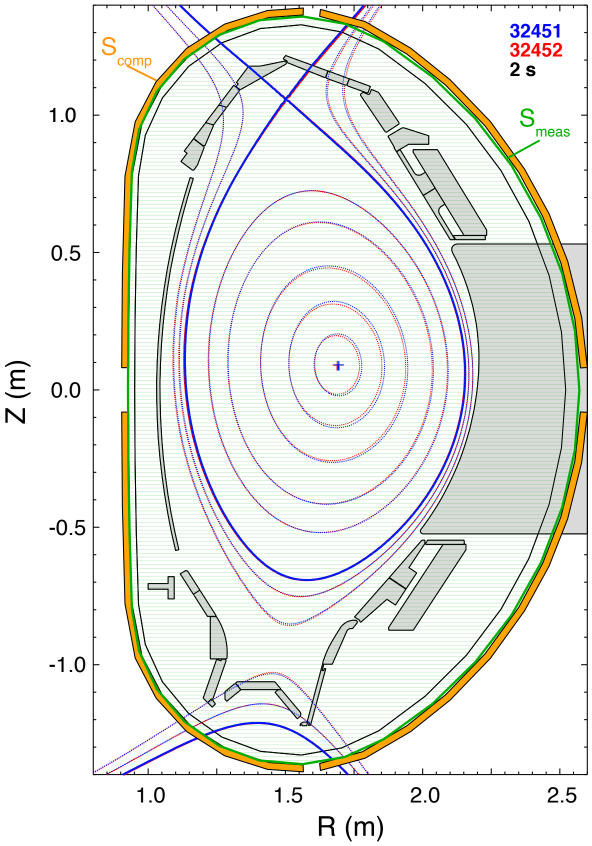

Figure 1: *Schematic diagram of the external diamagnetic loop on ASDEX Upgrade. The external measurement diamagnetic loop (green) is 2 turns mounted on a frame surrounding the vacuum vessel in the poloidal direction. The external compensation diamagnetic loop (yellow) is also mounted on this frame. The contours of the poloidal flux of the magnetic equilibrium for a discharge with negative (blue) and positive (red) toroidal field are also plotted.*

field coils, the coupled flux to the measurement and compensation coils of the external diamagnetic loop are recorded. The mutual inductance to each poloidal field coil can then be calculated so that the appropriate corrections during a plasma discharge can be applied.

TRANSP simulations

In Fig. 2, the measured diamagnetic flux is compared to that predicted by the TRANSP simulation for a discharge with neutral beam injection heating (NBI) and ion cyclotron resonance heating (ICRH). The poloidal beta inferred from the diamagnetic flux measurement, β_{DIA}, is in good agreement with the values calculated from the real-time and offline magnetic equilibrium reconstruction codes, β_{MHD}, in the steady state phase of the discharge.

In Fig. 3, the measured diamagnetic flux is shown for a discharge with dominant ion cyclotron resonance heating (ICRH). The diamagnetic flux predicted by TRANSP is plotted for 4 different fractions of coupled ICRH power. The power reflected by the ICRH antenna and line losses mean that only part of the nominal generator power is coupled to the plasma. Best

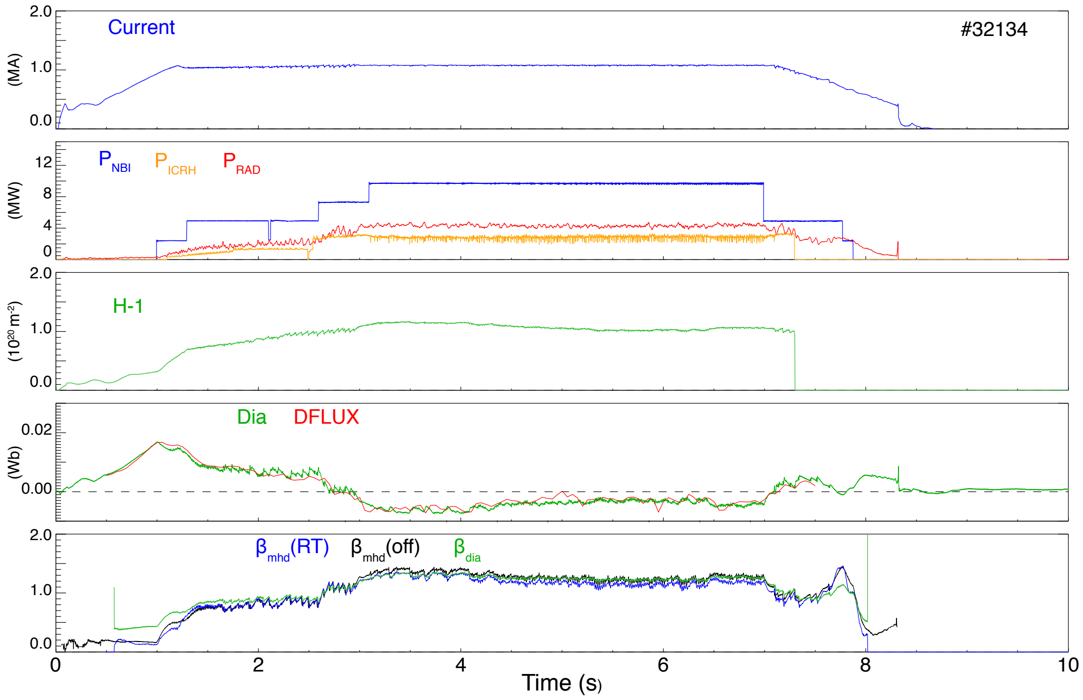

Figure 2: *Comparison of the diamagnetic flux and beta poloidal with the TRANSP simulation in a discharge with NBI and ICRH heating. The time evolution of the plasma current and the central electron density line integral of the DCN laser (H1) are shown. The measured diamagnetic flux, Dia (green), and predicted values from TRANSP, DFLUX (red), are in good agreement. The poloidal beta inferred from the measured diamagnetic flux, β_{DIA} (green), is in good agreement in the steady state phase of the discharge with the poloidal beta calculated from the real-time and offline magnetic equilibrium ($\beta_{MHD}(RT)$ (blue) and $\beta_{MHD}(off)$ (black)).*

agreement between the measured and predicted diamagnetic flux is found when only half the ICRH generator power is coupled into the plasma. This result suggests that a diamagnetic flux measurement and TRANSP simulation can be used together to estimate the coupled power in ICRH dominated discharges. The values of β_{MHD} calculated from the magnetic equilibrium reconstruction codes are lower than β_{DIA} inferred from the measured diamagnetic flux. This feature is expected for an anisotropic plasma, for example when the perpendicular pressure is greater than the parallel pressure.

Conclusion

Real-time diamagnetic flux measurements for ASDEX Upgrade are now in routine operation. The measurement and compensation coil integrators are initiated close to the flat top phase of the toroidal magnetic field prior to the start of the plasma current ramp. The measured diamagnetic flux and the prediction by TRANSP for the discharge with dominant NBI heating were found to be in good agreement. In this high density discharge with relatively low ICRH power,

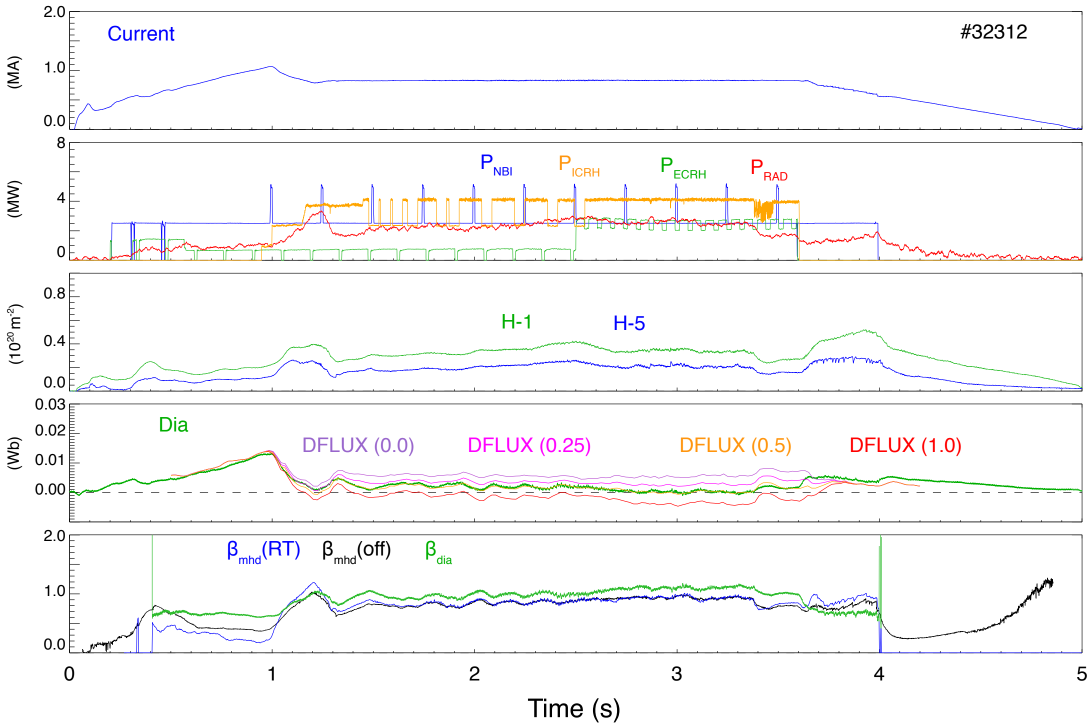

Figure 3: *Comparison of diamagnetic flux with the TRANSP simulation in a discharge with dominant ICRH power. The time evolution of the plasma current and the central and edge electron density line integrals of the DCN laser (H1 and H5) are shown. The measured diamagnetic flux, Dia (green) and the predicted values from TRANSP (DFLUX) for 4 different fractions of coupled ICRH power are shown. The plasma is anisotropic as the poloidal beta inferred from the measured diamagnetic flux,* β_{DIA} *(green), is greater than the poloidal beta calculated from the real-time and offline magnetic equilibrium (* $\beta_{MHD}(RT)$ *(blue) and* $\beta_{MHD}(off)$ *(black)) during predominant ICRH heating.*

fast ion populations do not play a significant role. In the discharge with dominant ICRH power and lower density, the best agreement between the measured diamagnetic flux and that predicted by TRANSP was found when it was assumed that only half the nominal generator input power was coupled. The fast ion population generated in this discharge must be taken into account when comparing diamagnetic flux measurements and TRANSP simulations.

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