

Compact shunts for the upper divertor of ASDEX Upgrade

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Introduction

To support the study of advanced X-divertor and snowflake divertor configurations produced by the new upper divertor coils recently installed in the ASDEX Upgrade [1], it is necessary to measure the thermocurrent using shunt resistors that have been mounted in the upper divertor tiles. A thermoelectric voltage is generated by the plasma electron temperature difference in front of the two target plates of the divertor cassette. This voltage is then taken out of the vessel via two leads, digitised, and analysed to determine whether the current is flowing into or out of the tile [2]. This measurement is also used for feedback control of the heat flux to the target plates via impurity gas puffing, thereby avoiding damage to the plasma-facing components [3].

Construction

A schematic diagram of the compact shunt, built according to the NSTX design [4], is shown in Fig. 1. A thin metal foil conducts the current from the tile surface to the backplane and the current can be determined by measuring the voltage drop across the shunt. Fig. 2 shows the CAD drawing of the compact shunt, with the tiles in the upper divertor labelled. There are four sets of five tiles with shunts located at 90-degree intervals around the torus. Fig. 3 shows the shunt construction (left) and the mounting of the tiles on the inner upper divertor (right). The compact shunt in ASDEX Upgrade uses an Inconel 718 sheet measuring $l = 5$ cm, $w = 2.5$ cm and $h = 0.3$ mm, the nominal shunt resistance is 7.5 milliohms.

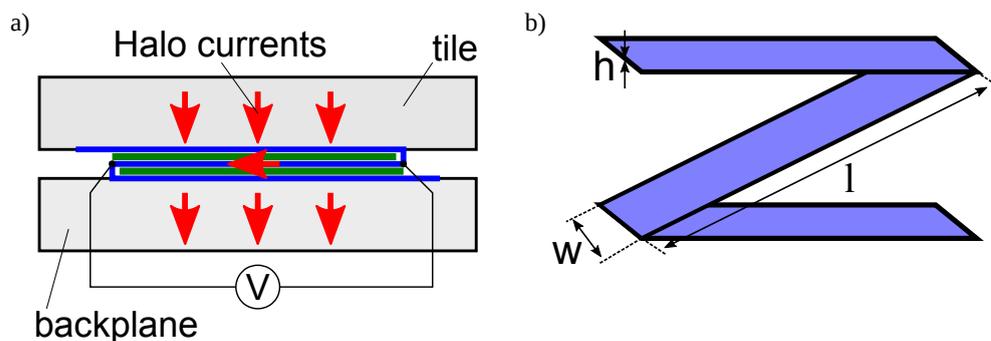


Fig. 1 Schematic diagram of compact shunt showing (a) current path and (b) relevant dimensions. (Color scheme: blue=resistor material, green=isolator)

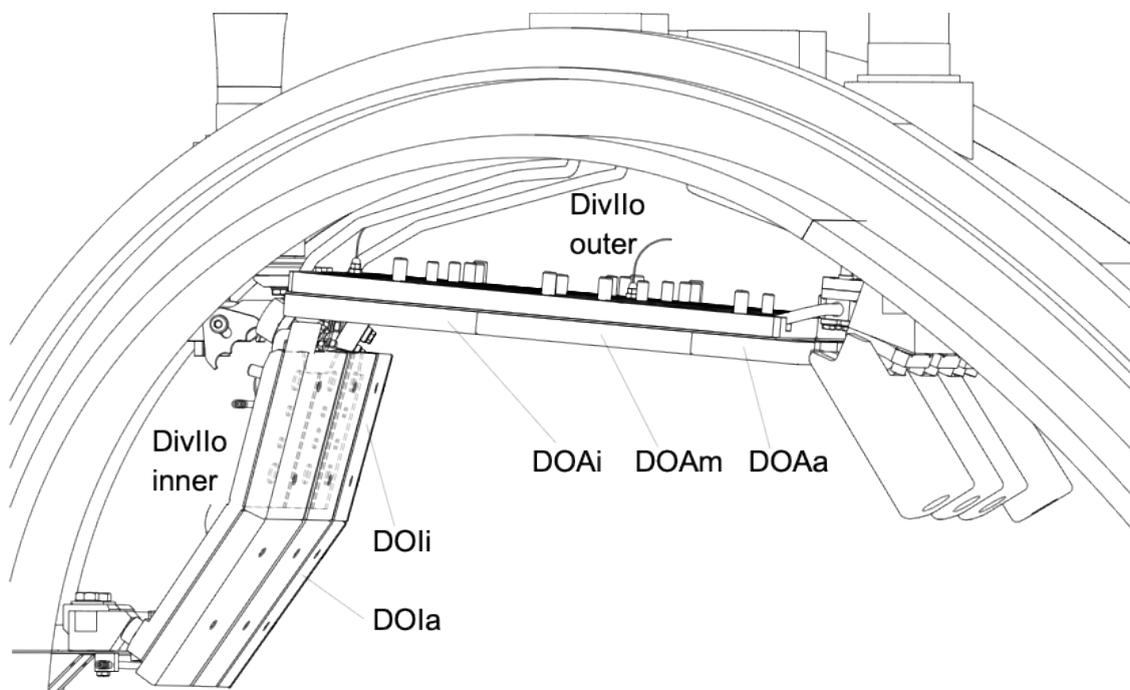


Fig. 2 CAD of a compact shunt showing the naming of tiles in the upper divertor. In a toroidal circumference, there are 48 tiles of the outer divertor and 64 tiles of the inner divertor.

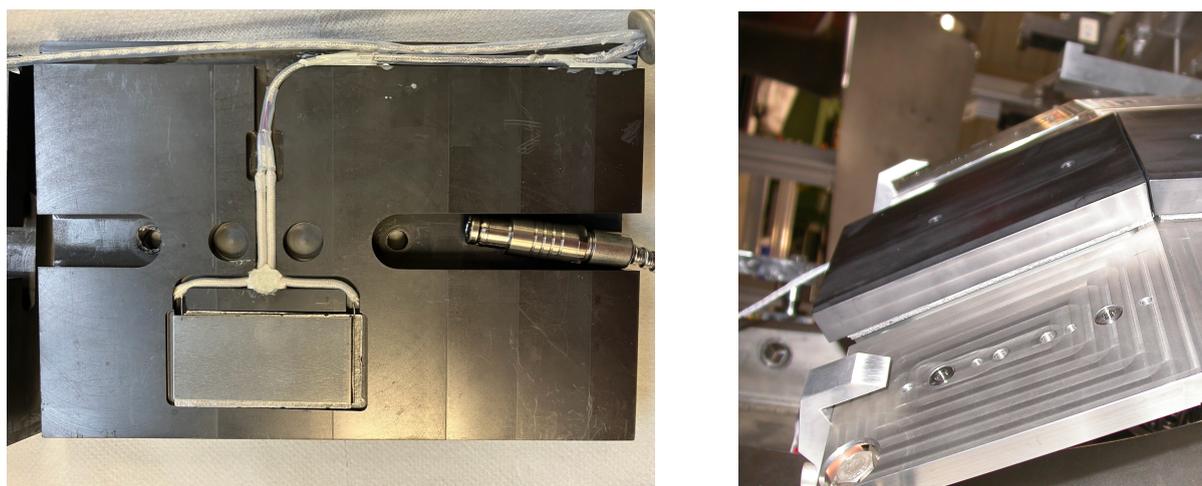


Fig. 3 Tiles showing shunt construction (left) and mounting of the tiles on the inner upper divertor (right)

Calibration

A 10 A, 50 Hz power supply is used, with one lead connected to the vacuum vessel and the other to a 2 cm diameter copper pad pressed against a tile. The current and voltage across the shunt are recorded. Cross-correlating the measured shunt voltage and current improves the signal-to-noise ratio of the calibration. Isolation amplifiers with a bandwidth of 25 kHz (Analog Devices AD-215) are used to isolate the signals from the data acquisition system. The shunts were calibrated as a function of frequency up to 20 kHz, and the phase shift between the current and shunt voltage was recorded. Assuming a series inductance with the shunt resistance yielded the best fit to the measured phase shifts for an inductance of 3.6 nH.

Results

Fig. 4 shows the shunt measurements obtained from sectors 2, 6, 10 and 14. In the presence of an $n=1$ mode, the shunt measurements exhibit $n=1$ mode characteristics with a 90-degree phase shift between the measurements taken 4 sectors apart.

An increase in the upper divertor current during a discharge causes the separatrix of the magnetic equilibrium to shift from the middle tile to the inner tile at the outer upper divertor. As illustrated in Fig. 5, the current pulses on the outer middle tile transition to pulses with significantly reduced fluctuations when the separatrix no longer makes contact with the tile. Initially, the shunt measurements on the outer inner tile also exhibit reduced fluctuations, but then change to pulses that are characteristic of edge-localised modes (ELMs) once the separatrix has made contact with the tile. Interestingly, a toroidal asymmetry is present in the middle tile measurements obtained during the phase when there is no current in the upper divertor coils. After 1.3 seconds, the direction of the current flowing through the middle outer tile in section 14 reverses. It now flows in the opposite direction to the other three sections. This time point coincides with the transition to H-mode, which indicates toroidal asymmetry in the plasma's attachment to the divertor.

In an X-point radiator discharge [5] in the upper divertor, ELM suppression was confirmed by shunt measurements. The location of the radiating volume in relation to the X-point depends on seeding and heating power levels.

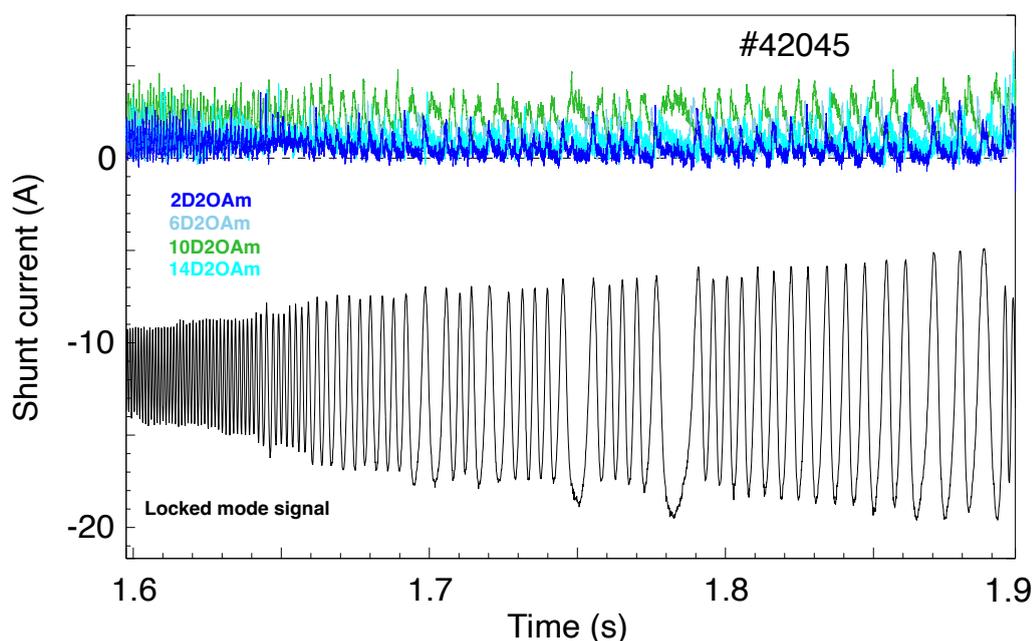


Fig. 4 In the presence of an $n=1$ locked mode, the shunt measurements display an $n=1$ mode character.

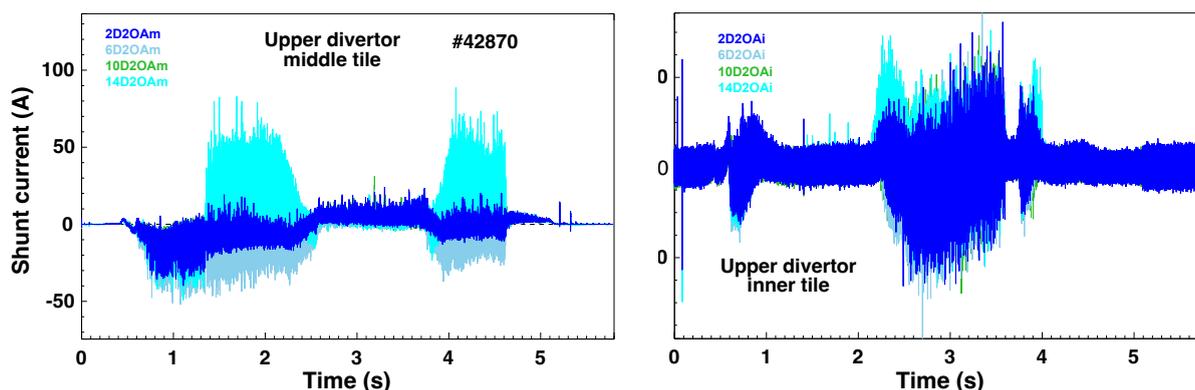


Fig. 5 The shunt measurements of two neighbouring upper outer divertor tiles (middle (left) and inner (right)) responds to changes in the strike point of the magnetic equilibrium when current flows in the upper divertor coil.

Conclusion

The compact shunts that are mounted in the upper divertor of ASDEX Upgrade are now in operation. An $n=1$ MHD locked mode produces shunt measurements that exhibit $n=1$ mode characteristics. During a discharge involving an upper divertor coil current pulse, the change in the equilibrium flux surfaces alters the separatrix contact point on the tile. The shunt measurements change depending on when the separatrix makes contact with the tile. Additionally, the current in the outer middle tile shunt in section 14 sometimes flows in the opposite direction to the shunts in the other three sectors. This occurs at the time of the H-mode transition, indicating toroidal asymmetry in the plasma's attachment to the divertor.

References

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