Plasma induced arcs in remote areas of ASDEX Upgrade

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Introduction

Arcing as a phenomenon at the first wall in fusion experiments is known for more than 30 years [1]. The occurrence of arcs was concluded from arc tracks found during in-vessel inspections and in post mortem laboratory investigations. In ASDEX Upgrade 3 groups of arcs are found: (i) arcs on components that are connected via field lines to the Scrape Off Layer (SOL) plasma, (ii) arcs in remote areas, i.e. areas that are protected by limiters or other components against the SOL plasma and (iii) arcs at the passive stabilising loop (PSL). The main focus of research is on arcs that are related to the SOL region. These arcs are triggered during normal plasma operation with magnetic confinement as can be concluded from the perpendicular orientation of the arc tracks with respect to the local magnetic field. There are only a few measurements on SOL-arcs in tokamaks with a good temporal resolution [2,3]. The contribution of SOL-arcs to the overall impurity content is small compared to erosion rates deduced from spectroscopic measurements [2,4]. But (i) arcs can dominate the local erosion when a significant part of the tungsten coating is damaged. And (ii) arc tracks are usually detected at the non-strike line modules of the divertor [2,5]. No arcs are detected at the strike line modules itself, whereas the maximum of erosion due to sputtering is highest there as measured spectroscopically [4]. In addition to this toroidally symmetric arc distribution in the divertor region, routine in-vessel inspection of ASDEX Upgrade reveals regions in remote areas that are affected by arcs too. These arcs might be single events, i.e. an arc track is found once during years of operation or they happen at certain locations for certain discharge phases. As a result, a significant amount of material can be evaporated and parts of the machine might be destroyed. Due to the relatively high energy that is stored in the PSL arcs are burning there over a longer time and can be detected by standard video systems with 40 ms time resolution. Here droplets produced by arcs are detected over 2-5 frames, i.e. about 100-200 ms. Since video data is commonly available for all discharges a statistical analysis allows to identify the discharge phase that triggers and drives arcs.

This paper reports on investigations of arcs in remote areas, i.e. in the non-divertor region, in particular on arcs that are burning at the PSL and on components at vessel potential, where they are triggered during special phases of the plasma discharges.

Experiments

The arc events at the PSL, were either detected by a video monitoring system in an early operation phase of ASDEX Upgrade or found during routine in-vessel inspections. Currents flowing in the PSL and the voltage across the bridge connecting the upper and lower winding of the PSL saddle coil (Fig. 1) are measured routinely with 0.5 ms temporal resolution. The

PSL itself is fixed on 8 suspension gears and is kept in the centred position by 4 upper and 4 lower suspension arms. All fixing points are isolated by isolating bushes with an insulation length of about 10 mm.

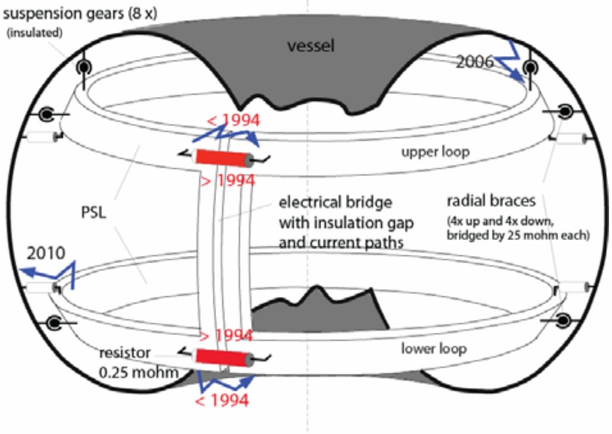

Fig. 1 Structure and arc location at the passive stabilizing loop (PSL).

To assure a well-defined potential situation, the PSL is connected the to the vessel potential via 20 mΩ shunts made from stainless steel cord. In addition arc events were detected during the shot campaign 2009 by the real time video protection system (VRT) of ASDEX Upgrade. These arcs are lasting about 100-200 ms and can be detected in a sequence of video frames. The time stamp allows a correlation of the events with phases of a plasma discharge.

Results and discussion

After the start of operation of ASDEX Upgrade in 1991, high current arcs were burning between the PSL conductors of the electrical bridge connecting the upper and lower loop. The high power arcs were melting a significant amount of material that splashes away without affecting the discharge. The direct damages were serious and the energy of the arc could also have allowed to cut water pipes with the consequence of a water leakage and an unscheduled opening. An open question still is the arc trigger mechanism. The voltage induced due to the changing PSL current $U_{ind} = -L\, dI/dt$ is well below the minimum voltage for arc breakdown of about 300 V without plasma. With plasma, the electrical fields caused by space charges in front of targets in plasma contact can achieve this level. But, the location, where arcs were observed was not connected by field lines to the SOL plasma and was partly protected against direct view to the plasma.

Nevertheless a pre-ionisation due to plasma radiation could not be excluded. To avoid more serious damage of in-vessel components, a few measures were taken to suppress the arcs. The isolation length was increased to about 15-20 mm and the insulation gap was protected against plasma view. But most effective was the installation of a water cooled shunt of 2x250 µΩ across the gap of the electrical bridge (red in Fig. 1). The value of the resistor was optimized by balancing the need of reducing the gap voltage by a low resistance and maintaining the capability to get a plasma break down because the induced current is driven in the PSL and not in the plasma itself. These measures taken in 1994 suppresses arc breakdown in the PSL conductors completely. In the following years very few high current arcs were observed at the PSL during in-vessel inspections. One event caused a melting at 4 upper suspension gears. Here arcs were burning across the insulation of the suspension gear. The amount of molten stainless steal was about 2x2 mm over a length of 80 mm. The energy to drive such a high current arc comes from the energy stored in the PSL conductor of typically $W_{PSL} = 0.5\,L I_{PSL}^2 \approx 0.5 \times 13 \mu H \times (10 kA)^2 = 0.65\,kW$.

A further event was the cut of the stainless steel cord shunt at one of the suspension arms.

Whereas high power arcs burning at the PSL or between PSL and vessel components are rare events, arcs burning on in-vessel components are much more frequent. Most of them were detected during in-vessel inspections. A few arcs were monitored accidentally in infrared cameras and video viewing systems. A systematic investigation of arc events was possible with data of the experimental campaign 2009 because arcs were burning at a dedicated position in the field of view of the real-time video protection system (VRT). The campaign comprises 640 useful plasma shots. The video data of these shots were analysed off-line with an algorithm that detects hot spots in a given field of view. The resulting pictures were analyzed by eye to verify that the detected events are really arcs and not artefacts. As a result arcs were detected in 26 shots or 4% of the total number of discharges. The in-vessel inspection reveals that the arcs were burning across insulating bushes. Such bushes are used for fixing structures to avoid induction loops due to multiple connections of in-vessel components to the vessel potential. In this special case 2 out of 4 bushes of a re-entrance port support structure were affected.

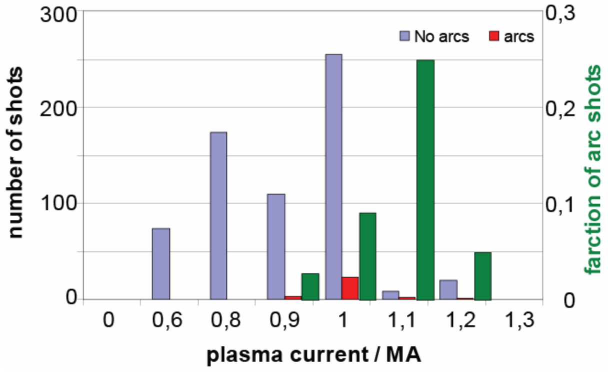

Fig. 2 Number of arcs in dependence of plasma current.

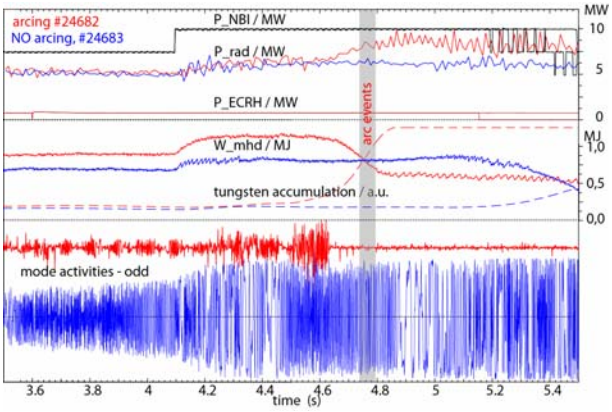

Fig. 3 Plasma parameters for shots with and without arcing.

An analysis of the discharge parameters reveals that the arcs are triggered in discharges with plasma currents > 0.9 MA as shown in Fig. 2. About 10 % of 313 high current discharges suffer from such arcs, whereas no arcs are detected in the 327 low current shots. There was no correlation found between the arc occurrence and the plasma stored energy or the energy confinement time.

The parameters of a pair of comparable discharges, one with, the other without arc are shown in Fig. 4. It is obvious that the arc was triggered in the discharge with higher plasma stored energy, W_{mhd}, however, in a phase with decreasing W_{mhd}. In addition, the discharge with arcs shows much less mode activities. 65% off all arc events were in phases with decreasing W_{mhd}.

This might be a chicken – egg problem, i.e. is the burning arc and the accompanied ejection of impurities the reason for the decay of plasma performance? To test this, the time delay between the onset of the W_{mhd} decay and the first video frame with an arc event was plotted in. The time delay is well above the time jitter of the data acquisition system with a maximum delay of 42 ms (1 full frame + 2ms interrupt time), i.e. the arc follows the W_{mhd} decay and is not the reason.

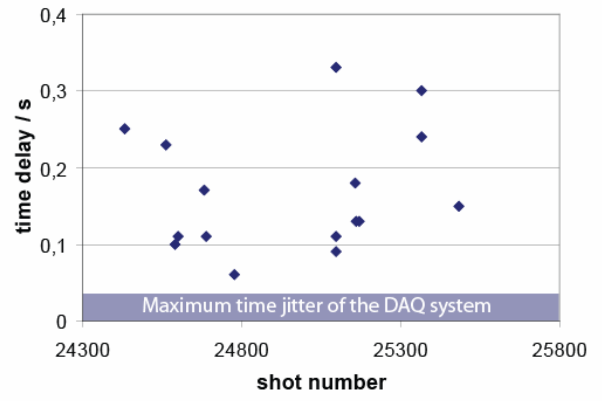

Fig. 4 Time delay of the occurrence of arcs in respect to the start of the W_{mhd} decay

W_{mhd} decays due to tungsten accumulation in the core plasma that starts already a few 100 ms before the plasma stored energy decays (see Fig. 4).

It is not clear yet, where the voltage for arc ignition is coming from. The loss of plasma performance accompanied by a movement of the plasma inducing a current in the PSL is too small (< 1 T/s) to produce significant voltages in the structure of the re-entrance port.

Summary

Three groups of arcs are detected in ASDEX Upgrade. Arcs are ignited at components in contact to the main/SOL plasma. These arcs are toroidally symmetric and are found in particular in the inner divertor and nearby areas. No arcs are detected at the strike line modules. Arcs in remote areas, i.e. areas without field line contact to the main plasma, are localized. Each in-vessel inspection reveals several new arc footprints. High power bipolar arcs are found at the passive stabilizing loop. The frequency of occurrence of burning arcs was significantly decreased by adding shunts across the electrical bridge gap. Nevertheless rare events melting grams of material are found. A systematic investigation of arcs detected by the video system at a dedicated position shows that arcs are triggered in discharges with plasma currents above 0.9 MA. 80% of these arcs are triggered in a discharge phase with decreasing plasma stored energy. The arcs are not the reason for the decay of the plasma stored energy. Arcing cannot be avoided in ASDEX Upgrade but in particular high power arcs can be controlled by carefully considering insulation gaps and using shunts to short cut potential differences.

References

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