

Arc discharges at the plasma periphery during disruption in tokamak

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Arc discharges at the plasma periphery are considered as important phenomena accompanying disruptions in tokamaks [1-3]. Effect of the arcs discharges could be especially strong in experiments with all-metal (*W*, *Be*, *V/Fe*) first wall [4-5] considered as baseline plasma-facing component in ITER. Present experiments in the T-10 tokamak ($R/a=1.5/0.3m$) have indicated that arc discharges could represent mechanism determining transition from relatively slow growth of the large-scale MHD perturbations to thermal quenches (minor disruptions) and subsequent transition to a major disruption with current collapse.

Arc discharges are studied in the T-10 tokamak with tungsten limiters in plasma with relatively high density. Effects of the arc discharges are evaluated by standard post-operational inspection of the first wall components and using movable magnetic and electrical probes (Fig.1) located near the plasma boundary at multiple positions inside the vacuum vessel. Fast magnetic probes *Mp1/Mp2* and *Mp3* are placed, accordingly, at the low and high field side of the torus in quadrant "A" close to the rail and circular limiters and *Mp4*, *HF1* in positions far from the limiters, at the low field side of the torus in quadrant "C". The probes are manufactured using nickel wire in ceramic isolation and are separated from the movable

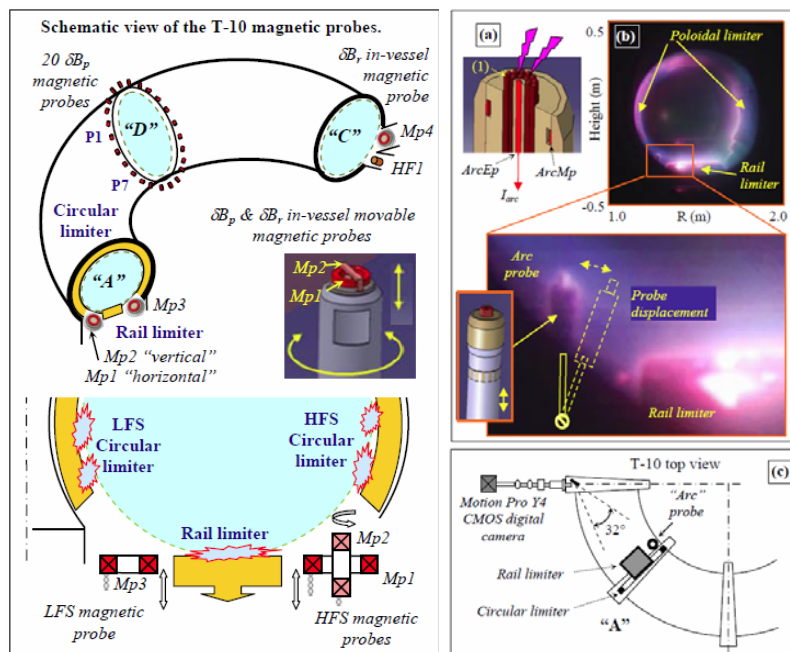


Fig.1. Schematic view of the T-10 tokamak and arc magnetic probes.

metallic rods by ceramic spacers. The probes *Mp1/Mp2* can be rotated around the vertical axis for measurements of the magnetic field distribution in the toroidal direction.

Essential new feature of the T-10 experiments is installation of the new "arc" probe (see Fig.1) with surface composed by multiple tungsten pins

($d \sim 1 \text{ mm}$) stimulating arc discharges at the probe. Arcs are identified by measurements of currents to the centrally placed isolated pin (*ArcEp*). Simultaneous measurements of the magnetic perturbations are provided by magnetic probe (*ArcMp*) placed close to the arc zone. The “arc” probe is placed in the lower part of the vacuum vessel at the high-field side of the torus. The “arc” probe can be positioned in vertical direction on pulse to pulse basis. Endoscopic optical system with high-speed CMOS digital camera Motion Pro Y4 (maximum resolution 1024×1024 , minimum exposure time $1 \mu\text{s}$, images with repetition rate 1 ms) is used for imaging of the visible light burst during arc activity.

Evolution of the plasma parameters in the T-10 experiments with disruption at high density is shown in Fig.2. New feature of the experiments is observation of the fast scale electromagnetic oscillations in the frequency range $f_{\text{fast}} \sim 0.2 - 0.5 \text{ MHz}$ superimposed with the standard large-scale $m/n=2/1$ and $m/n=1/1$ MHD modes during thermal quenches and subsequent major disruption (see *Mp1* and standard MM probe *P7* in Fig.2). The fast scale oscillations have maximum amplitude around the T-10 limiters and are characterised by strong decay with distance from the plasma edge (see Fig.3). Spatial decay rate and frequency of the fast scale electromagnetic oscillations are in agreement with arcs studies at the laboratory bench.

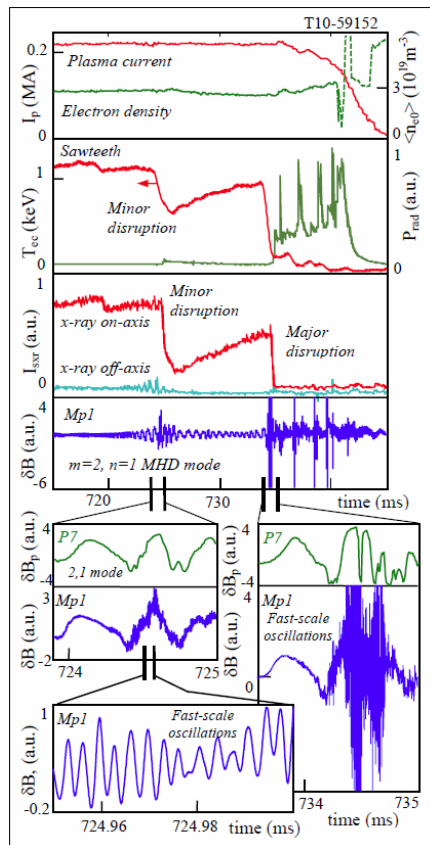


Fig.2. Temporal evolution of plasma parameters in the T-10 tokamak during disruption at high density. Fast-scale oscillations $f_{\text{fast}} \sim 0.2 - 0.5 \text{ MHz}$ are observed in addition to the large-scale $m/n = 2/1$ and $1/1$ MHD modes during subsequent energy quenches.

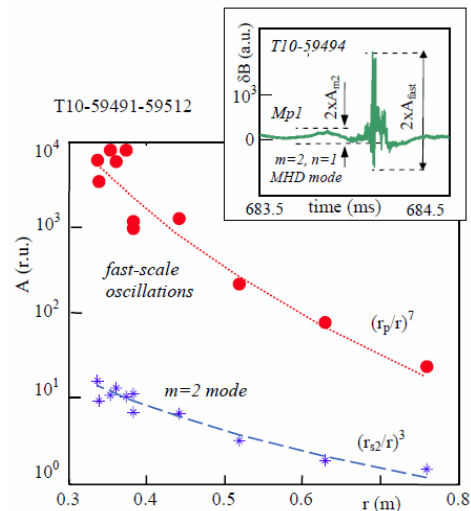


Fig.3. Amplitudes of the $m = 2$ MHD perturbations (stars) and fast-scale magnetic oscillations (circles) during disruption at high density measured using horizontal movable magnetic probe *Mp1* placed at various radial positions ($r_{s2} = 0.2 \text{ m}$, $r_p = 0.3 \text{ m}$).

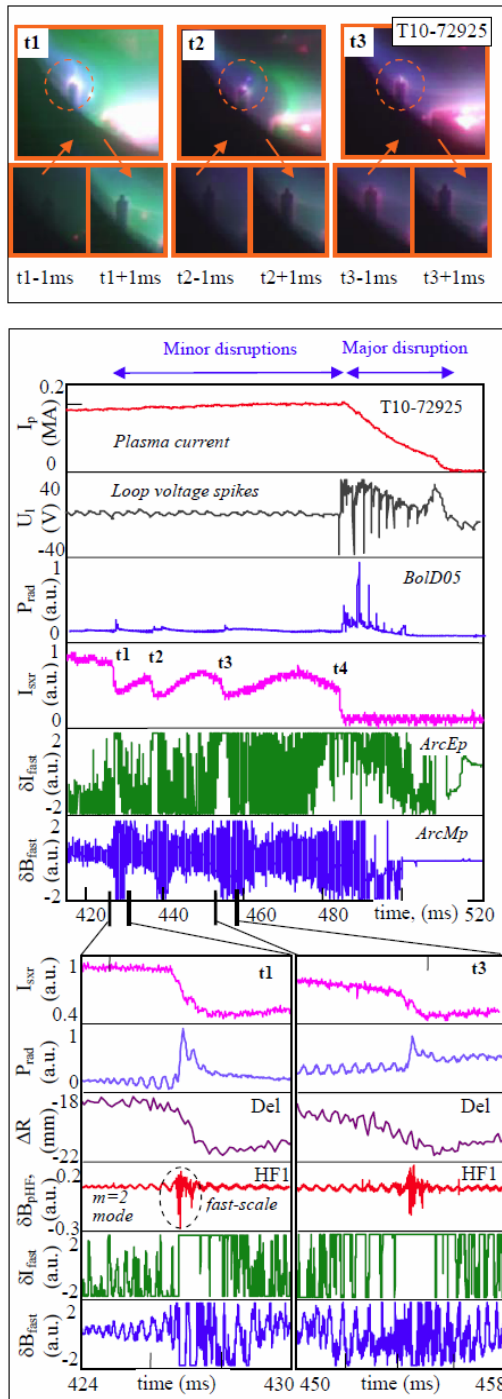


Fig.4. Images of the visible light intensity measured during thermal crashes during initial stage of disruption (see $t1$, $t2$, $t3$). Time evolution of plasma parameters in experiments with the "arc" probe.

Temporal evolution of the plasma parameters in experiments with the "arc" probe is shown in Fig.4. Major disruption (see $t > t4$, $t4 = 484.5$ ms) is preceded by series of minor energy crashes (see $t1, t2, t3$) accompanied by bursts of magnetic field perturbations and currents measured respectively with the Magnetic and Electric "arc" probes placed at the plasma boundary (see δB_{fast} and δI_{fast} in Fig.4 at $t > 420$ ms). A characteristic feature of the experiments with "arc" probe is change in the polarity of the signal of the Electric "arc" probe δI_{fast} from negative to positive at the moment of the thermal crashes. Positive polarity of the "arc" probe signal δI_{fast} indicates increase in the emission of the electrons from the probe surface. In the first thermal crash ($t1 = 426.8$ ms in Fig.4), the polarity change from negative to positive values occurs directly at the moment of the thermal crash during time interval $\Delta t \sim 2 \mu s$. After thermal crash, polarity of δI_{fast} returns to negative values after $\Delta t \sim 1 - 2$ ms (see $t > 428$ ms in Fig.4). Decrease in the values of signal to the electric "arc" probe δI_{fast} occurs simultaneously with reduction of the fast-scale magnetic oscillations. For subsequent thermal crashes (see for example crash marked by $t3$ in Fig.4), a polarity change is observed for a few milliseconds before the onset of thermal quench, simultaneously with growth of the large-scale $m = 2$ MHD mode. Thermal crashes are

characterized by enhanced plasma wall interaction resulted in bright spots of the visible light radiation at surfaces of the rail limited and at the tip of the "arc" probe.

Duration of the positive phase of the Electric "arc" probe signal δI_{fast} increases in series of thermal crashes. Moreover, Electric "arc" probe signal δI_{fast} becomes positive for a long

time at the stage of transition to major disruption (see $t > 478 \text{ ms}$ in Fig.5) which could be connected with multiple arcs. Electron emission from the probe reaches its maximum during major disruption. This is accompanied by fast displacement (inclination) of the “arc” probe along the major radius due to interaction of the current in the probe with the equilibrium toroidal magnetic field (see Fig.6). The displacement speed of the probe tip $v_R \sim 7 \text{ m/s}$ corresponds to the flow of total current $I_{\text{arc}} \sim 100 \text{ A}$. Analysis of the “arc” probe tip after experiments has indicated that strong plasma-probe interaction occur only at the innermost pin of the castellated surface. Assuming that current is flowing through the pin with area $S_a \sim 0.8 \text{ mm}^2$ one can obtain upper estimate of the arc current density $j_{\text{arc}} < 125 \text{ A/mm}^2$.

In conclusion, analysis of the T-10 experiments confirms appearance of the arc discharges during disruptions in tokamak. Increase of the plasma-wall interaction due to arcs could facilitate transition to the major disruption. Monitoring of the arc discharges at the plasma periphery could provide trigger for the disruption mitigation systems in tokamaks.

The work is supported by ROSATOM.

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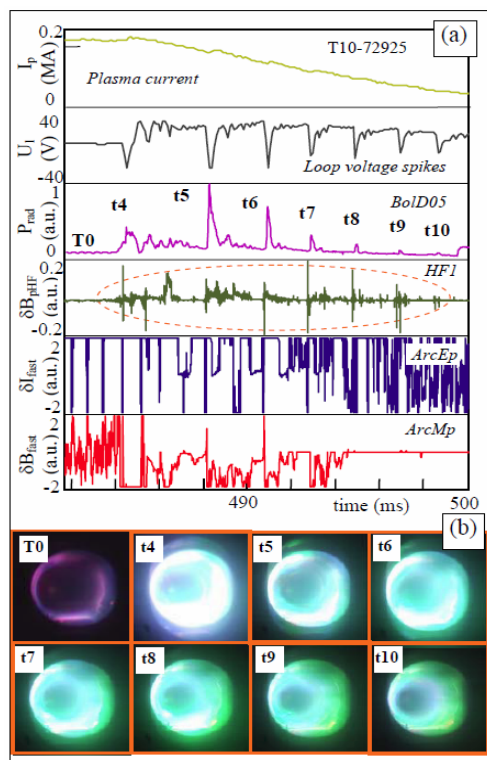


Fig.5. (a) Temporal evolution of plasma parameters during current decay stage of disruption in experiments with the “arc” probe. (b) Images of the visible light intensity measured during decay of the plasma current (see t_4 - t_{10}).

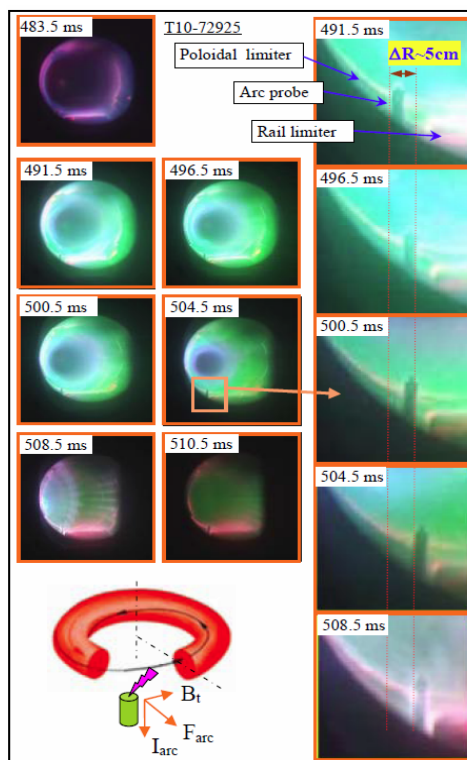


Fig.6. Images of the visible light radiations measured using endoscopic diagnostic at the final stage of the disruption. Also shown are enlarged images illustrating inclination of the “arc” probe from the vertical position (displacement along the major radius).