PECULIAR PROPERTIES OF DISRUPTION ON T-10 TOKOMAK AT DIFFERENT EDGE SAFETY FACTOR VALUES

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Abstract

One of the main goals of researching global plasma disruptions is to find a way to prevent the formation of runaway electron beams, after the plasma current disruption. A possible way to solve this problem is to generate of strong MHD perturbation during current decay. The experimental study of density limit disruption on tokamak T-10, for study of dependency a duration of plasma current decay \( t_{95} \) (from 100% to 5% of plasma current on quasi state stage of discharge) from edge safety factor \( q_a \) was carry out. As result, it was found that, if value \( q_a \) integer or half-integer than duration of plasma current decay is high increase, up to 100-115 ms. The main character feature of disruption with a slow current decay is absence of hard X-rays and high level MHD perturbation during all plasma current decay. Thus, from available experimental data, we can conclude, that during a slow current decay, high MHD activity lead to prevent the formation of runaway electron beams.

1. INTRODUCTION

Global plasma disruptions investigations are carrying out on many devices to find a way to prevent the formation of runaway electron beams after plasma current disruption. Interest in this problem is caused by the fact that if such beam intercepts a significant part of the plasma current, then it leads to a very serious danger for the plasma facing component [1-3]. One of the possible ways to solve this problem is generation of the strong MHD perturbations during plasma current decay [4-5].

2. EXPERIMENT

Experimental investigations of the duration plasma current decay under density limit disruption were carrying out on T-10 during long time. It was found that \( t_{95} \) (\( t_{95} \) is time of decreasing plasma current up to 5% from 100% of value on quasistate part of discharge) depends on the edge safety factor value: if \( q_a \) is integer or half-integer, then \( t_{95} \) is increased (up to 100-115 ms) (Fig. 1-2). Edge safety factor in that paper determines in cylindrical approximation. T – 10 is limiter tokamak with cylindrical cross section, major radius of vacuum vessel centre \( R = 1.5 \) m, minor radius of rail movable limiter in described experiment was a = 0.3 m and minor radius of aperture circular limiter \( a_1 = 0.33 \) m. Experiments was carried out with limiter from different material, from Graphite and from Tungsten and also without rail movable limiter. The dependency of duration plasma current decay from edge safety factor was observed independently from material of limiters or absence of movable limiter and character of dependency did not change qualitatively or quantitatively.

![FIG 1. Dependency of duration plasma current decay \( t_{95} \) from \( q_a \); red square C limiters, green circle W limiters](image1)

![FIG 2. Plasma current decay during disruption with \( q_a \approx 3.6 \) ( ); \( q_a \approx 3.5 \) ( ); \( q_a \approx 3.3 \) ( )](image2)
Plasma current force feedback system was turned off in moment when thermal quench was occurred, so power supply did not impact on current decay. The moment of thermal quench was determined by peak in signal of soft x - ray which occur in result of fast decreasing of electron temperature in that moment. Toroidal magnetic field and equilibrium control system did not switch off.

The increased duration of the current decay is uniquely linked to $q_a$. It was demonstrated in experiments where changing of the value of the toroidal field and plasma current with fixed $q_a$ does not lead to the change of the character and duration of the plasma current decay after disruption Fig. 3. It was impossible to determine plasma column displacement, after current disruption, by using magnetic coils. So for obtaining information about plasma column displacement during process of slow disruption, it was used measurements of chord profile of radiation losses with help AXUV detectors. Time evolution of shape and plasma column displacement is illustrated in Fig. 4. In that figure plasma displacement $\Delta R$ is determined as difference between major radius of vacuum vessel centre and major radius of the plasma column which given by maximum of radiation losses profile Fig. 5. From the analysis oscillography of plasma displacement $\Delta R$ it is possible conclude that at same time the plasma column moves to the high field side, multiple expansions and contractions of poloidal cross-section of current channel occur. The moment of time when the plasma column expands correlates with peaks on the loop voltage and with bursts on the MHD perturbation measured by Mirnov coils.

![Image 338x428 to 523x573](Image 338x428 to 523x573)

**FIG. 3.** The evolution of the plasma current after disruption for different toroidal fields and plasma currents before disruption, but with same integer edgy safety factor.

![Image 339x132 to 524x263](Image 339x132 to 524x263)

**FIG. 4.** Typical time evolution of signals during slow current decay: Mirnov coils (a), displacement of plasma column by major radius (b) and loop voltage (c).

On tokamak T-10 endoscopic optical system is used with high speed video camera for registration image of plasma in visible spectrum [6]. The location of endoscopic optical system allow us to view in the tangential direction the vacuum vessel cross section where were situated both limiters. From presented in Fig. 6 oscillogram of average luminance measured by endoscopic optical system it is possible conclude that burst of light, in result of intensive plasma interaction with limiter, happen after burst on signal of the MHD activity. Thus, changing of endoscopic optical system average luminance also show periodic expanding and contraction of the plasma cross section in moment of burst on the MHD perturbation signal.

![Image 453x489](Image 453x489)

**FIG. 5.** Chord profile of radiation losses before (--) and after (--) plasma current disruption

![Image 498x424](Image 498x424)

**FIG. 6.** Oscillogram of average luminance $I_{\text{LIGHT}}$ (--) and Mirnov coil signal $I_{\text{MHD}}$ (--)
Analysis of the spatial distribution of the poloidal magnetic field perturbation during slow current decay process (high $t_{95}$ value), shows that dominant perturbation is $m=2$ tearing mode Fig.7.

If suggest that characteristic time plasma current decay $t_{cQ} = L/R$ where $L$ is plasma self-inductance, $R$ is the plasma resistance then it is possible to estimate the electron temperature of the plasma during current quench.

Here $L$ can be given by $L = \mu_0 R_p (\ln(8 R_p/a) - 2 + l_i/2)$ where $a$ is the plasma minor radius, $R_p$ is the plasma major radius and $l_i$ is the plasma internal inductance. Plasma resistance can be evaluated as $R = \eta_\parallel (2\pi R / \pi a^2)$ where $\eta_\parallel$ is plasma specific resistance by Spitzer [7]:

$$\eta_\parallel = 0.53 \times 10^{-4} Z_{e,f} \ln\Lambda T_e^{-3/2}$$

Taking shot #69545 for example, measurements of electron temperature by electron cyclotron emission on second harmonic gives the electron temperature ~ 130 eV after thermal quench and with $R_p = 1.5$ m, $a = 0.3$ m, $l_i \sim 1.2$, $\ln\Lambda = 10$ and if takes $Z_{e,f} \sim 4$ temperature can be estimated by order of magnitude ~ 135 eV. Effective plasma charge has main impact on estimation of electron temperature, so it lay in range 100-150eV under variation of $Z_{e,f}$ from 3 to 5. Thus it is possible that after thermal quench in case of integer or half-integer edge safety factor electron temperature is high enough what lead to slow current decay. But it stays unknown why in case of integer or half integer edge safety factor not total energy losses happen.

Main peculiar property which was observed in disruption with slow current decay is absence of hard x-ray emission after current disruption. While in case of fast current decay hard x-ray emission after beginning of current decay was observed almost in every disruption Fig. 8. Also disruptions with slow current decay are characterized by low loop voltage in comparison with fast decay disruption Fig. 9.

**FIG. 7. Poloidal distribution of amplitude Mirnov coil**

**FIG. 8. Typical signals during disruption: hard x-ray (---) and plasma current (---)**

**FIG. 9. Raw signal of loop voltage in case of slow (---) and fast current decay (---)**
3. SUMMARY

As a result of the carry out experiments on the study of density limit disruption, it was found that duration of plasma current decay depend on plasma edge safety factor value. And in case of integer or half integer safety factor value duration of current decay high increase up to 100-110 ms. This effect was observed as with graphite limiters and with tungsten and also without rail movable limiter. From available experimental data it is possible suggest in case of half integer safety factor partial restoring electron temperature occurs, what do not happen in case not integer safety factor. Approximation of electron temperature gives a value of same order as the result of the measurements by using diagnostics of electron cyclotron emission. Perhaps relatively high electron temperature after thermal quench and high level of MHD activity lead to a condition in which the formation of runaway electron beams is prevented.

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