26th EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, 14 - 18 June 1999 ECA Vol.23J (1999) 1425 - 1428

A NEW PELLET INJECTION SYSTEM FOR SOFTENING OF DISRUPTION LOADS ON ASDEX UPGRADE

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1. Introduction - The injection of massive impurity pellets in a plasma has proved to be a method to reduce mechanical and thermal loads during disruptions in present tokamaks. Earlier experiments in ASDEX Upgrade [1] used frozen neon pellets, prepared in a cryostat and injected with a centrifuge. Since a cryo-system is not quite ideal for a stand-by application, typical of a disruption mitigation system, a new pellet gun for the injection of solid pellets was developed. The injector was designed, build and brought into operation on ASDEX Upgrade by the first author and the experiments were planned on the basis of the experience gathered in the previous years.

2. Technical specifications - The injector allows to inject pellets of 0.5-2.4 mm of diameter with a velocity of 100-500 m/s from the low-field side. The pellets used in this experiment were made of silicon (Si) or titanium (Ti) powder mixed with molten polyethylene (PE) and then extruded in the form of a cylinder. Spheres of 2 mm of diameter were then obtained by compression and heating. Si and Ti were chosen because of their "good" radiative properties and their acceptability in the machine; PE because of its relatively low sublimation energy and its acceptable chemical composition. The pellet velocities were in the range 200-250 m/s.

type	weight (mg)	N_I (I= Si or Ti)	grains (μm)	N_{CH_2}
Si (60 %) - PE	7 (4.2 Si)	$0.9\ 10^{20}$	15-20 (Si)	$1.2\ 10^{20}$
Ti (72 %) - PE	10 (7.2 Ti)	$0.9\ 10^{20}$	10 (Ti)	$1.2\ 10^{20}$

Weight and composition of the pellets used

3. Experimental data - Several experiments were carried out with the new injector in the period June-August 1998. We subdivide them in two main groups and discuss the experimental observations accordingly:

1) pellets injected with the timer in "healthy" plasmas, and

2) pellets injected with the locked-mode trigger in plasmas with locked modes and pre-disruption characteristics.

3.1. Group (1) - At the beginning of the experimental campaign the pellets were injected with a timer in order to test the injector and collect data in a variety of plasma conditions. The target plasmas did not have pre-disruption characteristics (no MARFE or/and locked-modes) and had a relatively high thermal energy. All these pellets caused a disruption with reduced mechanical forces (if compared with the forces in standard disruptions).

By means of several diagnostics we could observe the following sequence of events. The propellant gas (Helium) is seen reaching the plasma approx. 8 ms before the appearance of the pellet on the edge channels of the SXR cameras. Helium causes a degradation of the thermal energy of the order of 10 %. The pellet trajectory is nicely seen by the SXR cameras with the expected velocity. The SXR cameras also show the pellet flying from the edge to the q=1 surface of the plasma and the impurities rapidly diffusing within the q=1 surface. Independent of the plasma thermal energy the plasma disrupts typically after 2 ms from the appearance of the pellet at the plasma boundary (the pellet goes half way through the plasma).

The CCD camera has been the most convincing tool in determining the penetration depth of the pellets. The 13 pellets of this group were injected in plasmas with energies in the range 50-850 kJ. In plasmas with energies above 500 kJ the pellets seem to ablate almost completely before they leave the q=1 surface on the high field side; in plasmas with an energy below 500 kJ the pellets do not ablate completely (a residual fragment is always seen on the high field side). In the plasmas with energies around 100 kJ the pellets poorly ablate: the total radiated energy is only a factor of two larger than in a normal disruption (it was a factor of 10 larger with Ne pellets); the SXR cameras show ablation limited to the plasma central region; a visible light detector indicates that the ablation takes place within 15 cm. These results indicate that these pellets are overdimensioned for these plasmas. Nevertheless we are particularly interested in these low energy plasmas because pre-disruption plasmas have typically a low energy in ASDEX Upgrade.

3.2 Group (2) - In a successive experimental campaign several pellets were injected using the locked mode trigger. The locked mode detector, obtained by subtracting the signals of two saddle coils mounted on the high field side of the vacuum vessel, can detect toroidally asymmetric perturbations, such as the radial perturbation from a locked $(m = 2, n = 1)$ mode.

A fraction of the pellets were injected in the presence of a locked mode in plasmas with pre-disruption characteristics. Time traces of a few plasma measurements show in Fig. 1 the sequence of events already described for Group (1). Due to the relative large distance between injector and plasma (2.1 m) and the long time delay (20-25 ms) between trigger and pellet-in-plasma these pellets reached the plasma after the thermal quench. The propellant gas could have accelerated the evolution to the disruption. In a few cases the pellet enters the plasma at the time of the thermal quench, leaving open the possibility of disruption triggered by the pellet. The pellets which reached the plasma within a few ms after the onset of the disruption reduced the mechanical loads up to 50 % of the reference mechanical loads. Other measurements also confirm that the Si-PE pellets sufficiently ablated during the immediate post-disruption phase thanks to the presence of a large loop voltage and consequently fast electrons. Nevertheless there is no evidence of run-away electrons generated by the pellets.

The remaining fraction of the pellets was injected in plasmas with neoclassical locked modes, high beta and no pre-disruption characteristics; what has been said for group (1) is also valid for these pellets. It is worth pointing out here that an integrated disruption recognition system is necessary for the reliable use of the injector and that this system is under development [2].

4. Disruption loads - Disruptions after the injection of the impurity pellets had reduced halo currents and vertical forces (typically 50 % less). Figure 2 shows the distribution of the magnitude of the halo-current, normalized by Ip as function of the plasma energy. The figure was made with the following constraints: disruptions followed by vertical displacement of the plasma toward the bottom of the vessel, $k > 1.4$, flat-top and X-point plasma.

The picture shows that most of our plasmas disrupted with an energy in the range 0-300 kJ; all the pellets injected with the timer reduced the mechanical forces but were also in a energy range which is not typical for AUG; in the shots, in which the pellets reached the plasma during or after the disruption, the halo currents are also in the lower range.

5. Technical ameliorations - Since these experiments were made, several technical modifications of the injection system have been undertaken in order to improve its performance:

1) the injector was newly installed in sector 13 (earlier in sector 5) closer to the plasma (1.3 m); this and some additional changes in the injector allowed to improve its time response: pellets with a velocity of 250 m/s reached the plasma boundary 7 ms after the trigger;

2) a guiding tube and additional fast valves are going to be installed between injector and vessel in order to reduce the Helium ahead-stream and its influence on the plasma;

3) smaller pellets (cylinders of 0.8 mm of length and 0.8 mm of diameter) have been manufactured and 6 of them are going to replace one big pellet in order to increase the effective ablation surface and the ablation rate.

6. Conclusions - The new impurity pellet injector has been extensively tested with Si- or Ti-PE pellets: it has been proved to work in a reliable way and to fulfill its purposes of mitigating the disruption loads. A few technical modifications are going to allow a faster time response of less then 10 ms. The injector is planned to be routinely in stand-by and to be triggered by a disruption alarm system which is under development

References -

[1] G. Pautasso et al., **Nuclear Fusion 36** 1291 (1996)

[2] Ch. Tichmann et al., this conference

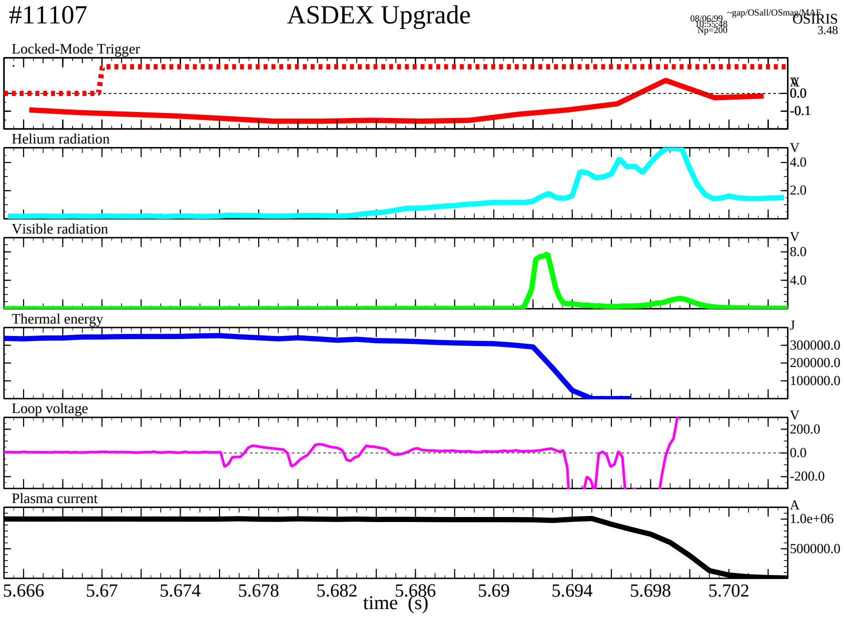

Figure 1. Sequence of events: locked mode trigger, helium radiation, pellet ablation and disruption.

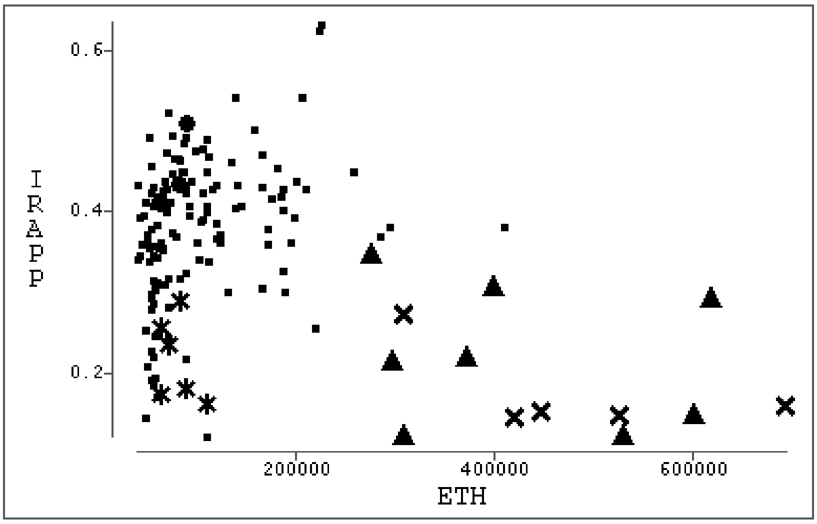

Figure 2. Ratio between halo current and plasma current versus plasma energy: shots without pellet (box), pellets injected with timer (triangle), with locked mode trigger in non-disruptive plasmas (X), with the locked-mode trigger about the time of the thermal quench (star) and with the locked-mode trigger late in the current decay phase (circle).