On reconnection nature of striations in ablating pellet clouds

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Introduction. Numerous experiments in tokamaks and helical systems have shown striations in ablating pellet clouds [1]. These non-homogeneities of the cloud radiation are seen both in averaged pellet track photos and in frames obtained using fast cameras with a microsecond resolution. Several mechanisms have been offered to explain the pellet cloud striations: Neuhauser (neutral shielding losses), Pegourie (depletion at rational magnetic surfaces), Parks (Relay-Taylor instability), Rozhansky (toroidal drift effects) (see [2]). However, all these approaches do not explain most bright features of the striations. Those are: enhancement of the ablation rate at rational magnetic surfaces accompanied with the toroidal pellet acceleration, motion of the striations with velocity up to 10 km/s in poloidal direction, observation of several clouds in pellet vicinity simultaneously with those having lower intensity as striations, necessity to have sufficiently large pellets for large striations (Kuteev, threshold effect [3]).

This paper is devoted to analysis of magnetic reconnection events forced by a pellet as the major mechanism for the striations. A scenario of striation development is described and estimations of the striation parameters are presented and compared with experimental data available.

Experimental data. The most detailed information on hydrogen pellet clouds structure and striations has still been obtained in T-10 experiments [4]. A fast framing camera VSK-5 has been used, which allowed us to get up to 70 film registered photos with 2 microsecond temporal resolution and ~ 7 microseconds time interval. The hydrogen pellet with the size of 1.4 mm was injected into plasma with the velocity ~ 600 m/s from the low field side at the angle of 30 degrees to the equatorial plain. The observation was arranged from equatorial plain, though shifts of the cloud in poloidal direction could be clearly seen in the cloud pictures. A typical set of cloud frames is presented in Fig 1. At the beginning of ablation (frames 11-19) the cloud shape becomes elongated along the magnetic field and no large striations are visible. The frame 20 is the first that indicates a sudden broadening of the cloud in the lower direction at ~1 cm size and immediate restoration of the size in frame 21. The largest cloud broadenings are seen in frames 26, 32, 37. The splitting in two clouds is evident in frames 45, 49, while may be 3 clouds are seen in frame 42. This last picture and time

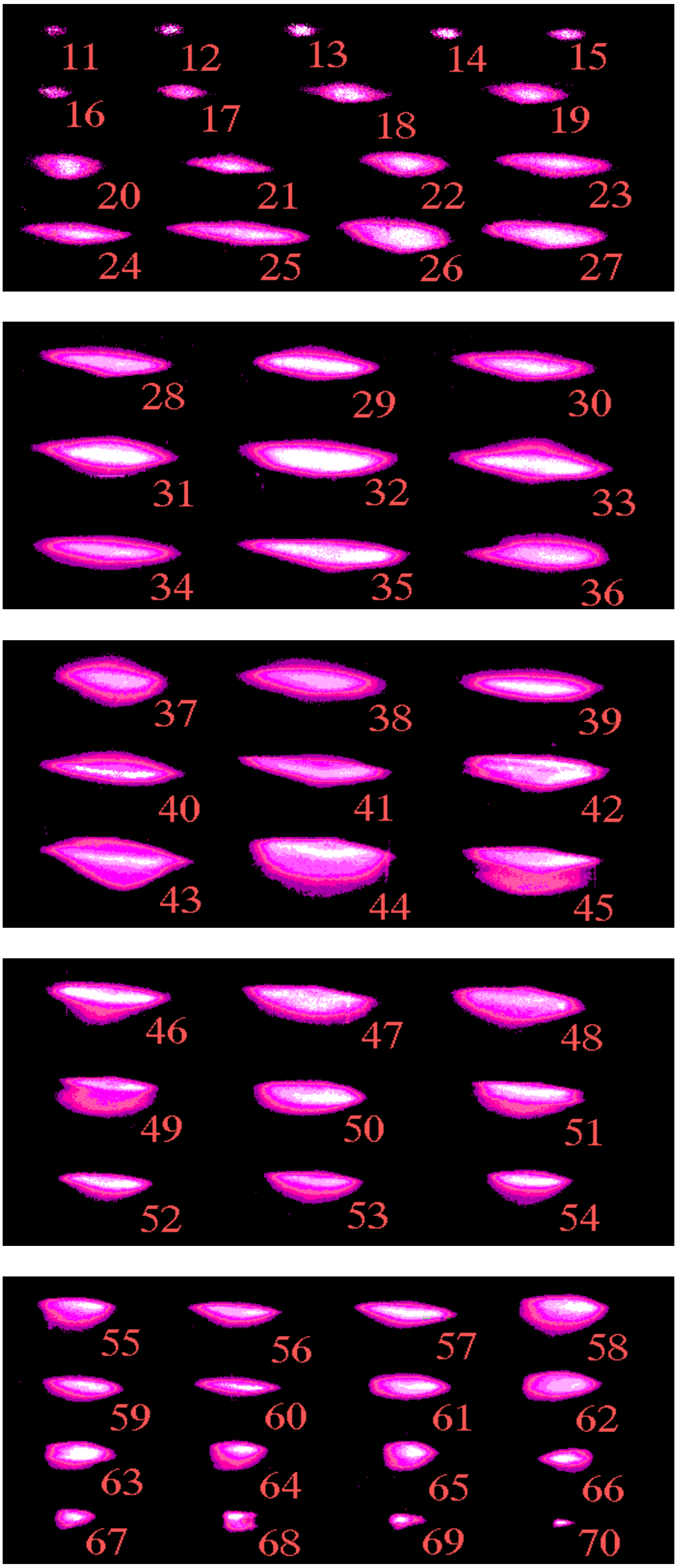

Fig. 1. Clouds evolution during pellet penetration into plasma

interval correspond to events nearby q=1 magnetic surface with large forced reconnection.

Model. The following scenario steps of the pellet image formation were considered. 1- A pellet crosses a rational MS with a low n, m. and initiates the x-point. 2. Due to a sufficient reduction of the electric conductivity it triggers magnetic reconnection which within a microsecond time interval transforms the magnetic energy of the reconnected region (a few cms in radial direction) into plasma cloud energy. 3. The plasma moves from x-point in poloidal directions with Alfven speed (~10 km/s) and forms two virtual neutral clouds. 4. These plasma flows are affected by polodal drifts due to radial electric fields E_r (~5 km/s), which may generate the cloud picture so that even only one additional cloud is distinguished. A schematic diagram of pellet cloud registration and expected cloud frames for different ration of the Alfven velocity v_A and the drift velocity in radial electric field E_r are shown in Fig.2. For $v_A >> v_{Er}$ the cloud image should contain real pellet cloud and two reconnection cloud. Comparable Alfven and drift velocities correspond to single additional cloud and extension of the real cloud in the opposite direction to the reconnection cloud moving with the summary velocity $v_A + v_{Er}$. In the case of high drift velocity a separate cloud and elongation in the drift direction is also possible.

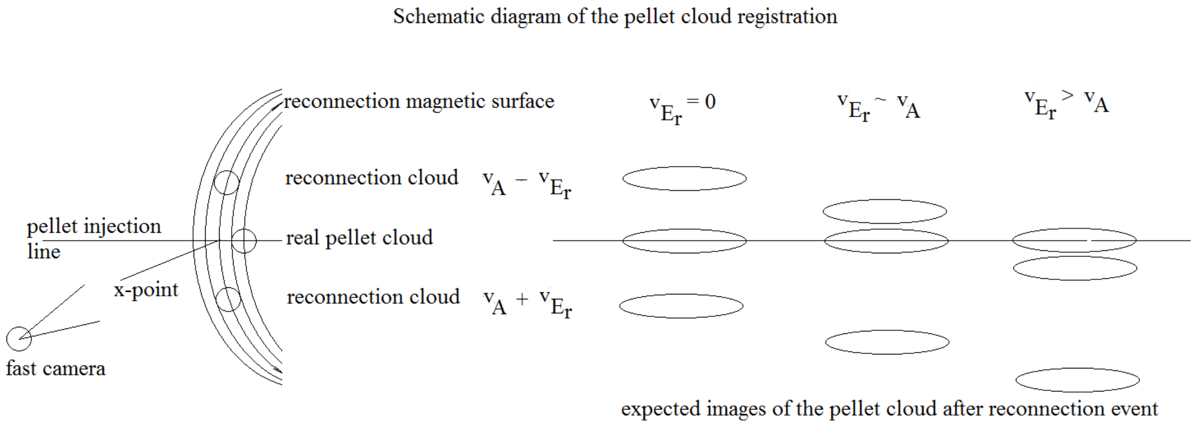

Fig.2. Schematic diagram of the pellet cloud registration

The Alfven velocity of the plasma flows in the reconnection region is about 3 km/s.

$$v_A = 2.18\times10^{16}\frac{B^*}{(2\cdot\mu_0\cdot M_i\cdot n_e)^{0.5}}$$

For B* ~0.1 T, $M_i = 2$, $n_e = 10^{23}$ m^{-3} this equation gives $v_A = 3.5$ km/s.

This value is comparable with an expected E_rxB drift velocity in tokamaks like T-10 and contemporary helical systems. Thus these tree options may be practically realized and observed in the experiments on T-10 and other devices.

Discussion. The experimental data presented are in qualitative agreement with the described hypothesis of the cloud image shaping. Frame 42 detected real cloud and two reconnection clouds in situation when $v_A >> v_{Er}$. The frames 45 and 49 distinguish real and one reconnection cloud. Registration of many images elongated in the E_rxB drift direction (downward) may correspond to the last situation with the reconnection cloud not seen in the picture due to reduced intensity.

Summary. The mechanism proposed is capable to explain the effects mentioned above and predicts the largest striations near q=1 magnetic surface where the magnetic reconnection energy is maximal. The sequence of reconnections during pellet ablation should not be periodic because it depends on concurrence of the ablation rate and the shear at x-point.

References

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