MHD-ACTIVITIES DURING PELLET INJECTION INTO OHMICALLY AND BEAM HEATED PLASMAS ON ASDEX

M. Kornherr, O. Gehre, K. Grassie, O. Klüber, V. Mertens and G. Becker, H.S. Bosch, H. Brocken, K. Büchl, A. Carlson, A. Eberhagen, G. Dodel[1], H.-U. Fahrbach, G. Fussmann, J. Gernhardt, G. v.Gierke, E. Glock, O. Gruber, G. Haas, W. Herrmann, J. Hofmann, A. Izvozchikov[2], E. Holzhauer[1], K. Hübner[3], G. Janeschitz, F. Karger, M. Kaufmann, K. Lackner, R. Lang, M. Lenoci, G. Lisitano, F. Mast, H.M. Mayer, K. McCormick, D. Meisel, E.R. Müller, H. Murmann, J. Neuhauser, H. Niedermeyer, A. Pietrzyk[4], W. Poschenrieder, H. Rapp, H. Riedler, A. Rudyj, W. Sandmann, F. Schneider, C. Setzensack, G. Siller, E. Speth, F. Söldner, A.Stäbler, K. Steinmetz, K.-H. Steuer, N. Tsois[5], S. Ugniewski[6], O. Vollmer, F. Wagner, D. Zasche

Max-Planck-Institut für Plasmaphysik
EURATOM Association, Garching, FRG

Introduction

The combination of gas-puff and pellet refuelling provides ohmic discharges with nearly twice the confinement time and 1.5 times the Murakami limit /1/. Despite these improvements, the density built-up by a string of pellets (up to 80 pellets with maximally 700 m/s and up to 50 pellets per s) is not yet optimized. There are phases where the pellet refuelling leads to a step-like increase in density followed by those where the added mass is quickly lost between pellets. The gradual loss of density is often accompanied by a step-like decrease such that no effective density increase remains. It is interesting to note, that during these ineffective phases β does not continue to increase but may even decrease.

In this paper we describe in detail the MHD-activities during pellet injection, studied essentially with two soft-X-ray ("SX") cameras. Fig. 1 exhibits the toroidal positions of the viewed poloidal cross sections of these cameras and of the HCN-laser-interferometry in relation to the pellet injector, furthermore, the directions of the toroidal and poloidal magnetic field lines and both neutral beam injectors.

Plasma dynamics caused by pellets.

The injection of a pellet leads to a strong localized density disturbence, which is not immediately distributed over the magnetic flux surfaces, but causes a characteristic dynamic response of the plasma, which can be well studied by observing the rapidly changing SX profiles. Fig. 2 gives an example of the spatial and temporal variations of both radiation profiles in horizontal and vertical direction after an injection of a pellet into an ohmic discharge ($\bar{n} = 4 \times 10^{13}$ cm^{-3}, $I_p = 380$ kA, $q_a = 2.9$).

Within a few hundred µs a poloidally strong asymmetric distribution of SX radiation develops. The measured signals of the chords crossing the outer

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[1] University of Stuttgart; [2] Ioffe Institute; [3] University of Heidelberg; [4] University of Washington, Seattle, USA; [5] N.R.C.N.S. "Democritos", Athens, Greece; [6] Inst. for Nuclear Research, Swierk, Poland

and lower halfs of the plasma cross section decrease, while the signals of the inner and upper chords increase. This m=1 like structure rotates within the viewed cross section in direction of the poloidal magnetic field lines with a typical frequency of about 1 kHz and is damped after 2 - 10 cycles. Only the edge-localized channels (omitted in Fig. 2) show a different behaviour, namely a single positive spike due to the injected pellet.

After injection of a pellet into an ohmic discharge with reversed toroidal field and plasma current the maxima and minima of the SX signals become exchanged (cf. Fig. 3); also the direction of rotation alters and corresponds again to the direction of the poloidal field lines.

In this context the following observation from HCN-interferometry is of interest: Immediately after pellet injection the lower laser beam is deflected for both magnetic field directions. This diffraction indicates strong density gradients but in both cases within the lower plasma region, passing the HCN laser beam.

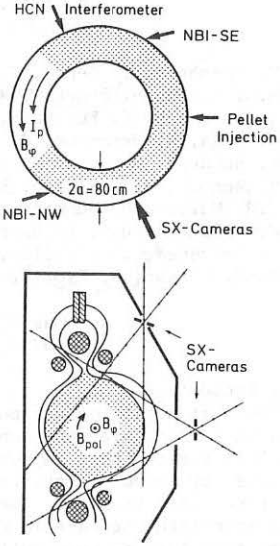
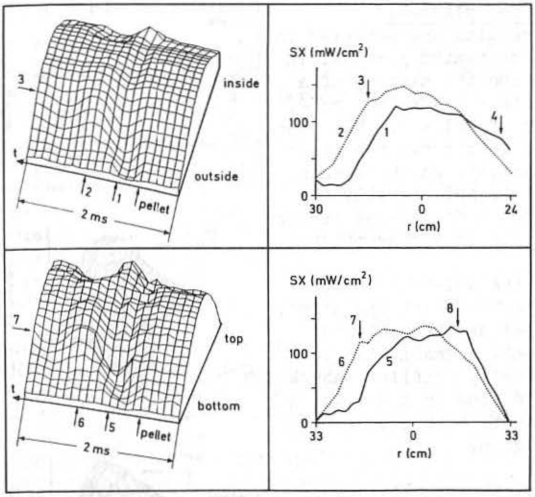


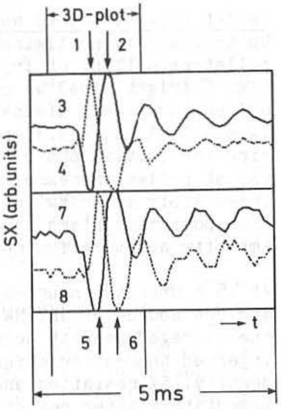
Fig.1: Schematic design of the ASDEX device.

Sawtooth activity and accumulation.

The oscillatory mode described before finally leads to a new static SX profile. The integral radiation increases from pellet to pellet and the profile becomes more and more peaked. Already after a few pellets the sawtooth activity may increase and on the time scale of typically 20 msec after pellet injection one or more strong sawteeth occur. In the example of Fig. 4 strong sawteeth are observed after the third pellet, accompanied by distinct steps on the density trace. Despite the broadening by sawteeth the density profiles remain strongly peaked in the case of pellet refuelling, which originates from an increased inward drift /2/. This enhanced drift causes also accumulation of impurities in the plasma center /3/.

In Fig. 5 two discharges are compared which only differ in plasma current. Smaller currents correspond to more peaked density profiles /4/. In both discharges a string of five pellets is injected and the temporal behaviour of the discharge is very similar. After the last pellet a strong sawtooth occurs. In case A strong sawteeth stop the further development of the accumulation phase and restore the original plasma parameters, in case B with smaller plasma current the sawteeth become suppressed and the enhanced inward drift leads to strong accumulation of electron density and heavy impurities in the plasma center. Accumulation and sawtooth activity are competing processes and the temporal development of pellet refuelled ohmic discharges depends ultimately on the strenght of the two counteracting processes.





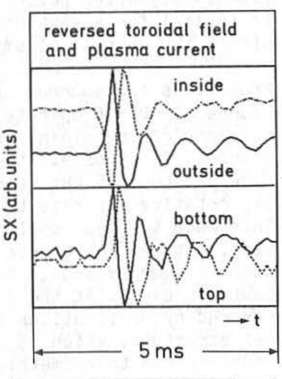
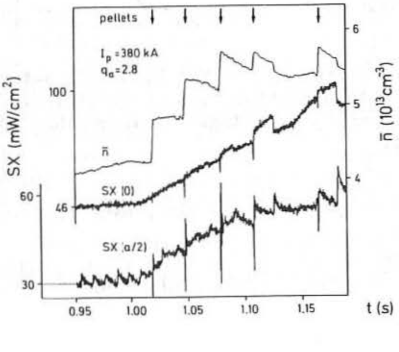


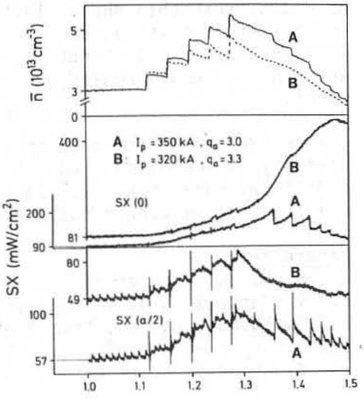
Fig.2 (above): The spatial and temporal development of SX radiation after pellet injection into an ohmic discharge. Identic numbers correspond to identic SX signals.

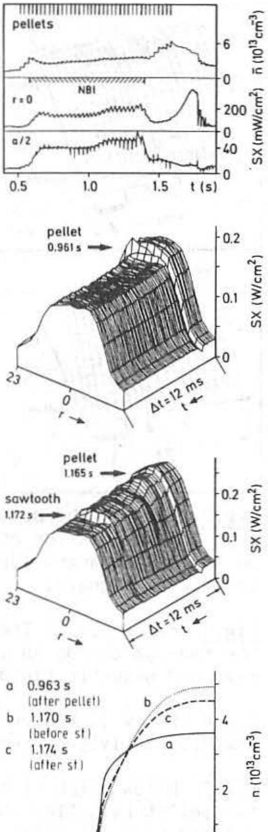
Fig.3 (right side): The temporal development of the same SX chords as shown in Fig. 2, but at reversed magnetic fields.

Fig.4 (below left side): Development of strong sawtooth activity after pellet injection.

Fig.5 (below right side): Comparison of two pellet refuelled ohmic discharges w/o and with accumulation, respectively.







Pellet injection into NB-heated plasmas.

Up to now only preliminary results are achieved in pellet-refuelling of injection heated plasmas. In Fig. 6 (right side) we describe the history of a NBI heated plasma discharge ($\bar{n} = 1.4 \times 10^{13}$ cm^{-3}, $I_p = 320$ kA, $q_a = 3.3$, power of NBI = 1.3 MW). During the initial ohmic phase we observe the typical step-like increase in density, which repeats immediately after switching off NBI; finally the transport mechanisms described before cause strong impurity accumulation resulting in a disruption.

At .6 s when two sources of the NBI-SE injector and one source of NBI-NW injector start operation, the averaged density decreases and the pellets injected thereafter effect only a small rise in density. SX radiation and density profiles change immediately after pellet injection in a way which is typical for a sawtooth event, both become flat within the central plasma region.

From 1.0 s two sources of NBI-NW and only one source of NBI-SE operate; at the same time the response of the plasma upon an injected pellet changes. First of all the pellet excites an m=1 mode of about 15 kHz near the inversion radius of SX, rotating opposite to the ion drift direction. This mode becomes completely damped after about 10 msec, but reappears once more with slightly reduced frequency and is finally terminated by a sawtooth event. At the same time we observe corresponding oscillations on Mirnov loops with m=4, n=1 structure, which is well explained by mode coupling due to geometrical effects /5/. There is no doubt, that this MHD-activity is triggered by the pellet, but it can also occur in NBI heated plasmas without pellet refuelling. SX radiation and density remain peaked up to the sawtooth event.

The broadening of the density profiles caused by the two kinds of sawtooth activity as described does not lead to an essential loss of particles. The additional mass of pellets is lost rather in a gradual way accompanied by simultaneous peaking density profiles.

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