Interpretative Simulations of Pellet Fuelled JET-Plasmas

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Pellet injection is a promising technique for fuelling and density profile control of fusion grade plasmas, especially for future tokamaks with high power amplification, like ITER-FEAT. In order to understand experiments and to perform reliable predictive simulations of ITER scenarios the realistic modelling of pellet injections in combination with appropriate transport models is of high importance. Lang et al. [1] have experimentally demonstrated the dependence of fuelling effectivity and maximum demonstration depth on the poloidal injection angle. That effect is due to the drift of the plasmoid down the gradient of the magnetic field and the plasma cooling generated by the plasmoid. Those effects are contained in the physical model of the PELDEP-code [2]. Furthermore, a region of poor confinement caused by ELMs of a H-mode and recycling can be included into the simulations. In an upgraded version referred to as PELDEP2D [3] two-dimensional effects like off-center injection are modelled. Fig.1 shows the sensitivity of the fuelling effectivity on the injection angle an on the distance R_{eq} [4]. This quantity characterizes the off-center injection and is defined as the distance between the magnetic axis and the intersection of the pellet trajectory with the horizontal line containing the plasma center. This figure shows for a JET-plasma the incease of fuelling effictivity if the launching angle appoaches π. The dependence of R_{eq} is relatively small if the off-centricity is small and decreases dramatically when R_{eq} becomes large. Fig.2 shows also the dependence of the fuelling effectivity on the launching angle for three different elongations. The small reduction of fuelling effectivity at about $\pi/2$ is related to the existence of a Shafranov shift. That effect does not play an important role for realistic elongations, e.g. $\kappa = 1.6$.

The combination of PELDEP respectively PELDEP2D with a transport code presents an important tool for simulations of fusion plasmas. We have combined the pellet routines with the well-known transport code ASTRA [4]. The pellet routine provides now the particle source density S_p for the continuity equation.

$$\frac{1}{V}\frac{\partial}{\partial t}\left(V'n_i\right)+\frac{1}{V}\frac{\partial}{\partial \rho}\Gamma_i = S_p - S_f$$

V' is the derivative of the volume of the flux surface with respect to ρ, where ρ is the generalized radius ρ. The fusion source, which is important for predictive simulations of ITER, is represented by S_f. The radial component of the ion flux Γ_i is composed of a neoclassical part Γ_{neo} and of an anomalous term Γ_{an}

$$\Gamma_i = \Gamma_{neo} \quad \Gamma_{an}$$

Γ_{neo} contains also the convective term of the transport model. Thus the inward velocity is purely neoclassical. We have assumed that the anomalous transport can be represented by a gradient law

$$\Gamma_{an} = -D_{an}\frac{dn_i}{d\rho}$$

The anomalous diffusion coefficient D_{an} is in our model related to the heat conduction coefficients for electrons χ_e and for ions χ_i by the widely used relation

$$D_{an} = S(\rho)\frac{\chi_i\chi_e}{\chi_i + \chi_e}$$

The ad hoc function $S(\rho)$ is assumed to have a parabolic shape with $S(0)=1$ and $S(a)=0.3$. The heat conduction coefficients have been calculated by the mixed Bohm/gyroBohm model from Taroni [6].

A lot of JET discharge with pellet injection have been analysed. In all analyses ASTRA has taken the experimental temperature profiles of electrons and ions. As an example we present the analysis of the JET-shot #53212. It is a type I ELMy mode plasma which is fuelled by multi-pellet injection. That shot has been chosen because of its high ITER relevance with respect to density and heating.

The time evolution of the plasma current may be seen in Fig.3. The plasma current rises to 2,5 MA. The plasma is heated by neutral beams. The NBI-power injected into the plasma during a period of 10 seconds amounts to 18 MW. The oscillations in the power curve is due to ohmic heating. The NBI heating has been simulated by combining the ASTRA code by an NBI package described in Ref.[4]

The fuelling scheme is shown in Fig.4. At first, from t = 40 s to t = 56 the plasma is fuelled by gas injection. In this figure the number of the puffed gas particles are drawn versus time. Afterwards pellet injection is started at about t = 58. A suite of 17 pellet injections takes place. The resulting line-integrated density is shown in Fig.4. All pellet are injected from the inner side. In Fig.5 the line-integrated density is shown again as a function of the time. In this figure we have drawn the velocity of the injected pellets and the timepoints of injection. It is seen that the pellet velocities are about 150 m/s.

As an example Fig.6 presents a comparison of experimental density profiles and profiles obtained by numerical simulation by means of our ASTRA/PELDEP system. The broken lines refer to experimental profiles and the full lines to results of the simulation. That figure demonstrates a very good agreement of the experimental and the simulated curves. This agreement has been found in many examples, if some experimental parameters like homgeneization time and mass drift are well estimated. A selfconsistent model to calculate those quantities is highly desirable. The estimation of the depth of the zone of bad confinement and of the recycling factor have a strong influence on the simulations. Of course the transport model plays a crucial role for successful simulations.

We have demonstrated that by the presented combination of the advanced pellet code PELDEP2D with the ASTRA-system provides a reliable tool for simulating pellet fuelled plasma discharges.

References

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[3] L. Garzotti, PELDEP2D, private communication, 2003

[4] L. Garzotti, G. Kamelander et al., 30th EPS Conf. St.Petersburg, Vol.27A, P-1.089, 2003

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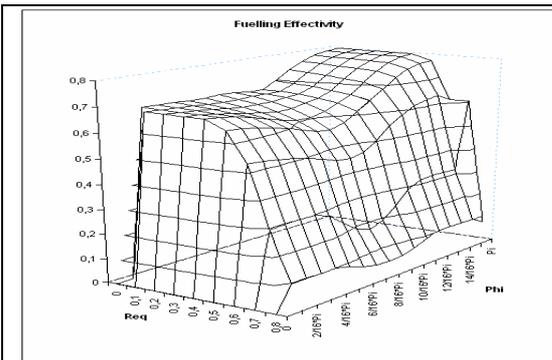[6] A.Taroni et al., Plasma Phys. Control. Fusion, 36,629 (1994)

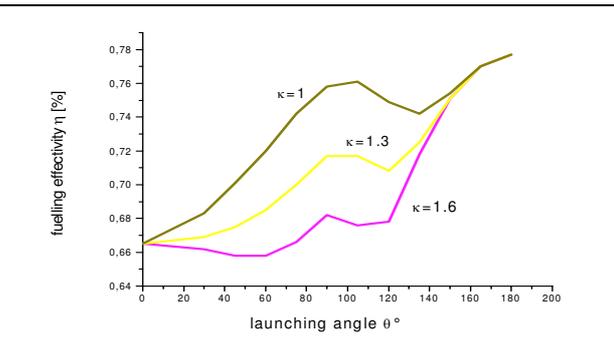Fig.1. Fuelling efficiency vs. R_{eq} and ϑ

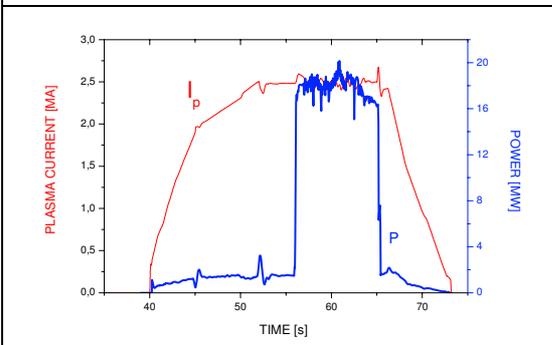Fig.2. Fuelling efficeny vs. launching angle for the elongations κ =1., 1.3 and 1.6

Fig 3: I_p and P_{tot} in shot #53212

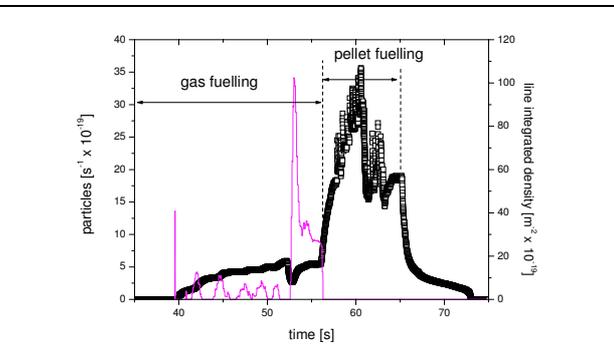Fig.4: gas puffing and $n_{l\text{int}}$ in shot #53212

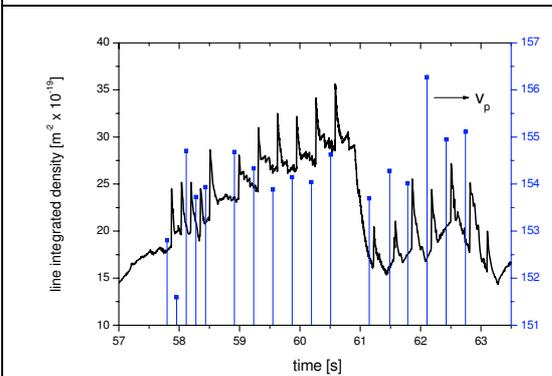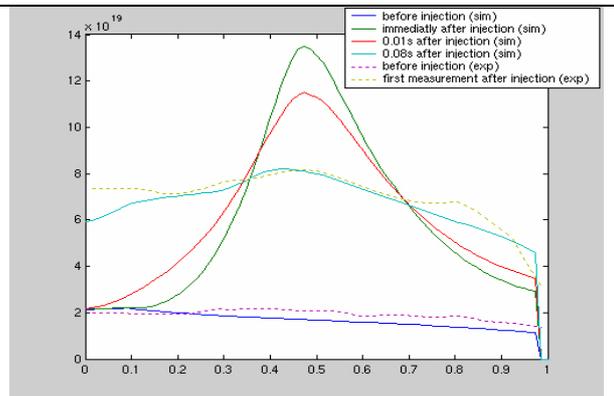Fig.5: $n_{l\text{int}}$ and pellet injection in #53212

Fig.6 Experimental and simulated density profiles for the first pellet injection profiles