INTERACTION OF COLD HIGH-DENSITY PARTICLE CLOUDS WITH MAGNETICALLY CONFINED PLASMAS

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The sudden release of a large number of neutral particles subjected to subsequent ionization has found application in fusion research as well as in other plasma-physical areas, e.g. magnetospheric experiments. Although the physical conditions are vastly different in these experiments, there are some fundamental similarities between the respective cloud expansion processes. In all these cases the released neutral particles expand in a spherically symmetric manner until they become ionized. As a result of ionization and subsequent interaction with the magnetic field, the transverse expansion of the cloud is slowed down and brought to a full stop. The radially confined plasma is 'funnelled' into magnetic flux tubes: its expansion along the magnetic field lines is practically a vacuum expansion. The expanding plasma distorts the magnetic field: a transient magnetic cavity may form inside the cloud. Since the cloud is heated by the incident plasma particles, the incident energy flux is a function of the species present in the plasma and, in the case of energy carriers with gyro-radii less than the cloud radius, of the diamagnetic state of the particle cloud.

A variable-mass single-fluid single-cell Lagrangean model was developed to describe and analyze the above processes, with implementation primarily to pellet-plasma interaction studies. The rate of the cloud mass variation, i.e. the strength of the mass source attached, is specified by means of a pellet ablation routine coupled to the cloud expansion model: the ablation rate is given at any time instant as a function of the temperature and density of the cloud particles sorrounding the mass source.

The model was tested by means of data of earlier magnetospheric barium cloud experiments where the characteristic time and length scales range from 100 s to 1000 s and from 10 km to 500 km, respectively. Sudden particle release (instantaneous ablation) was assumed in this case. Detailed calculations were performed for hydrogen clouds associated with the injection of pellets into tokamak plasmas. The characteristic time and length scales in this case are of the order of 1 μs to 100 μs and 1 mm to 50 mm, respectively (see [1] and [2]).

The time histories of all relevant cloud parameters (which, besides determining the strength of the mass source, represent massive local perturbations for the recipient plasma), of such as its radius, length, temperature, pressure, ionization degree, beta value, lifetime, internal magnetic field strength, etc, are computed for various (total) cloud masses, ablation rates, magnetic field strengths, plasma temperatures, and are analyzed.

Some representative results corresponding to pellet injection scenarios in ASDEX and JET are shown in Figs. 1 and 2. Here the time development of various pellet cloud parameters and local plasma disturbances are shown for a given number of pellet particles deposited between two flux surfaces. If the pellet injection velocity is given, the mass source strength can be calculated on the basis of the residence time of the pellet in the flux tube considered. The number of particles locally deposited is taken either from experimental measurements (ASDEX: Shot No. 18716/1.624 s, see Fig. 1) or ablation calculations (JET: see Ref. [3]). The local ablation rate was computed in this case by means of the ablation model proposed by Houlberg et al. [4]. Constant ablation rate (e.g. linearly increasing ablatant cloud mass) was assumed for the residence time of the pellet in the flux tube considered.

In Fig. 1 the time development of the cloud size (radius, length) and of the transverse velocity of the cloud boundary are shown. The transverse deceleration of the cloud mass involves Alfvén time scales. The maximum cloud radius is defined by the relative magnitudes of the pellet mass locally deposited, the heat flux affecting it (ionization time), and the magnetic field strength applied. The expansion along the magnetic field lines and the return to equilibrium conditions involves hydrodynamic time scales which are by three orders of magnitude larger than the Alfvén time scale. The maximum (calculated) beta reached in the plasma cloud of Fig. 1 was ~ 0.05, the maximum electron density was about $1.2 \times 10^{23} m^{-3}$.

In Fig. 2 the time histories of the magnetic field strength, electron density, and beta are shown for the JET scenario considered. In this case, the plasmoid radius reached after a few overdamped oscillations is about 1.4 cm.

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References

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[4] W.A. Houlberg, S.L. Milora, and S.E. Attenberger, Neutral and Plasma Shielding Model for Pellet Ablation, Nucl. Fusion (to appear in 1988).

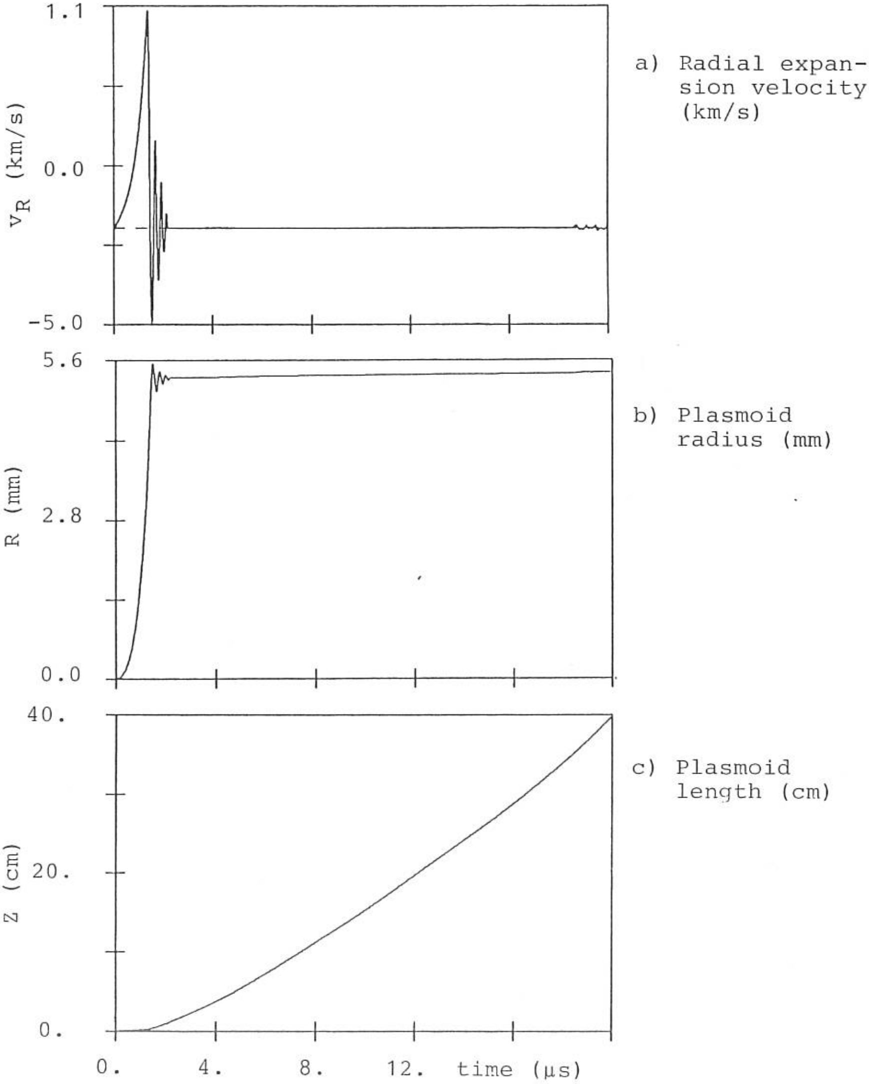

Fig. 1: Time development of a pellet cloud in ASDEX (Shot No. 18716/1.624 s): $N = 2.53 \times 10^{18}$ particles deposited between r = 28 and 29 cm, $v_p = 650$ m/s.

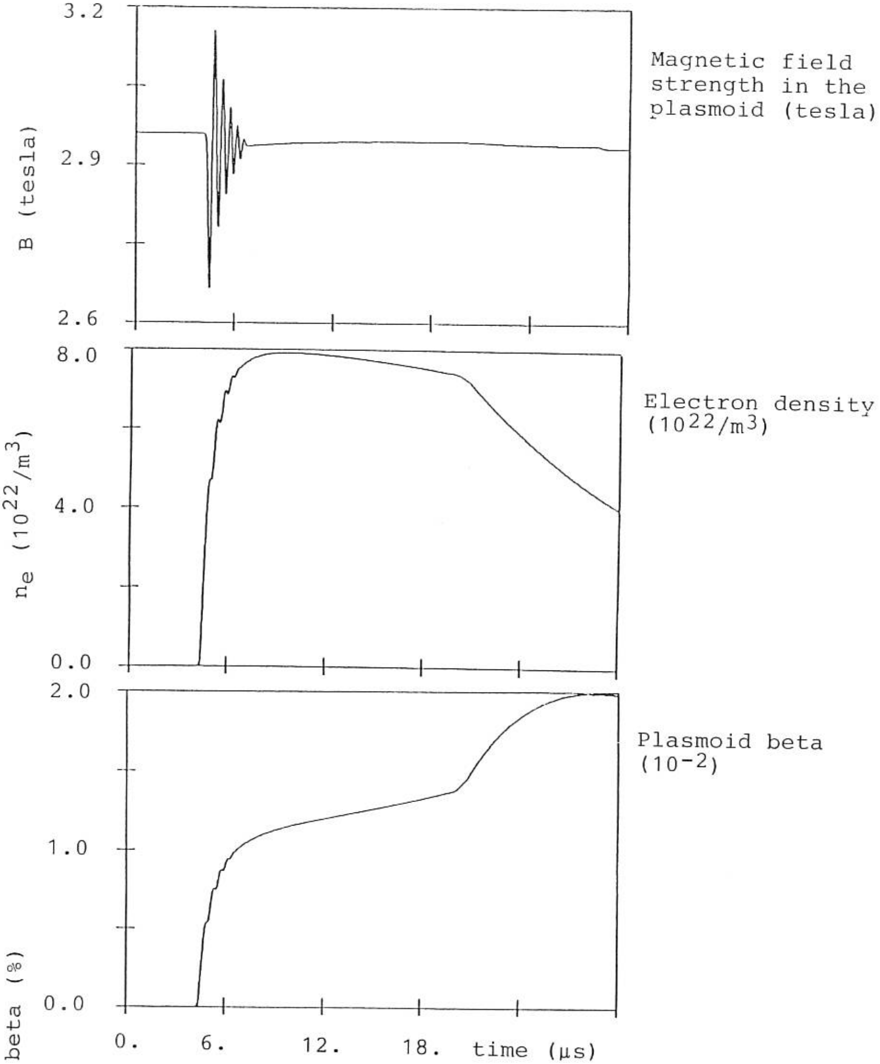

Fig. 2: Time development of plasmoid characteristics in JET at $r = 0.9$ m, $\Delta r \approx 2.0$ cm; $N = 2.2 \times 10^{19}$ particles are deposited within 20 µs.