*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.109 (2008)*

Assessment of Pumping Requirements in ITER for Pellet Fuelling and ELM Pace Making

A.R. Polevoi[1], A.S. Kukushkin[1], W. Houlberg[1], S. Maruyama[1], K. Gál[2], P. Lang[3], B. Pegourie[4], H. Nehme[4], M. Sugihara[1], A. Loarte[1], D. Campbell[1], V.A.Chuyanov[1]

[1]ITER Organization, Cadarache, France, [2]MTA KFKI RMKI, Budapest, Hungary, [3]Max-Planck-Inst. für Plasmaphysik, Garching, Germany, [4]CEA, Cadarache, France

Abstract. Here we analyze requirements for tritium plant fuel processing and pumping systems in order to accommodate a combination of high field side (HFS) and low field side (LFS) injection for independent core fuelling and ELM pace making. The reduction of fuelling due to particle loss produced by ELMs and loss in the guide tubes is taken into account. A variety of options are considered to provide balanced D and T fuelling.

Introduction

Pellet injection is considered as the basic core fuelling technique as well as a possible tool for ELM pace making in ITER [1]. Drift of the ablated pellet particles in the direction of the low magnetic field makes possible to control fuelling and ELM pace making independently by a combination of HFS and LFS injection [2]. It is assumed (conservatively) that the pellet must penetrate to the top of the edge pedestal to produce ELMs [3]. The pellet injection frequency, $f = f_{LFS} + f_{HFS}$, is determined by the requirements for tolerable ELM energy loss, $f\sim(\Delta W_{ELM})^{-1}$ [4]. Pellet penetration depth increases with pellet speed and size. The maximum pellet speed is limited by the intact pellet production and depends on the guide tube curvature and diameter [5]. The number of particles per pellet, N_{pel}, is limited by the capacity of tritium production plant and pumping system, $N_{pel,LFS}\, f_{LFS} + N_{pel,HFS}\, f_{HFS} = N_{pel,LFS}\,(f- f_{HFS}) + N_{pel,HFS}\, f_{HFS} < S_{max}$.

Pellet size and speed

The intact pellet speed is limited by the guide tube curvature – for HFS injection in ITER this is 300 m/s with 10% loss in the guide tube. The maximum pellet speed in the LFS guide can be higher, 500 – 1000 m/s. In our analysis we use the largest pellets from different models (Fig. 1) predicted to be sufficient to penetrate to the top of pedestal for reference pedestal parameters (Fig.2) and for the pellet injection design geometry of ITER (Fig.3). The minimum size of pellets for HFS and LFS injection at maximum speeds are: $C_{ext}\, N_{pel,HFS} \sim 4.2\ 10^{21}$, $C_{ext}\, N_{pel,LFS} \sim 2\ 10^{21}$ - $5\ 10^{20}$. Here $C_{ext} = 0.9$, takes into account the loss in the tube.

Pellet frequency

The pellet injection frequency, f, is determined from the empirical scaling [4]: ΔW_{ELM} f = α P_{sep}, with α = 0.2 - 0.4, as a function of the power loss through separatrix, P_{sep}. Erosion of the divertor plate is negligible for power density per ELM: Q_{ELM} < 0.5 MJ/m^2 [6]. For strong in/out asymmetry of the ELM power loss in the divertor, P_{out}/P_{in} = 1 : 2 [7], and the ELM affected area, S_{in}= 1.3 m^2, the tolerable ELM energy loss is $\Delta W_{ELM} = Q_{ELM} \times S_{in} \times (1 + P_{out}/P_{in}) \approx 1$ MJ, which corresponds to 1% of the expected pedestal energy, $\Delta W_{ELM}/W_{ped}$ = 1%. For the power scale expected in ITER, P_{sep} ~ 100 MW, the required injection frequency, f = $f_{LFS} + f_{HFS}$ = 20 – 40 Hz for α = 0.2 - 0.4.

Fuelling efficiency

An ELM causes particle loss from the plasma. For purely convective loss in the ELM, this loss can be estimated as $S_{ELM} = - N_{plasm} (\Delta W_{ELM}/W_{ped})$ f. Therefore, the ideal efficiency of the core fuelling by HFS pellets is: $\Delta N_{plasm}/N_{pel} = 1 - (N_{plasm}/N_{pel}) (\Delta W_{ELM}/W_{ped})$. The number of particles in the core in the reference inductive scenario is $N_{plasm} = 8.3\ 10^{22}$. Then the fuelling efficiency can be expressed as $\Delta N_{plasm}/N_{pel} = 1 – 8.3\ 10^{20}/ N_{pel}$ (see Fig. 3). A negative value of the efficiency means here that the particle loss with the pellet-induced ELM exceeds HFS core fuelling by the pellet.

Particle balance

The required core fuelling, $S_{DT,core}$, depends on the particle transport. A range of core fuelling requirements is considered, which corresponds to the uncertainty in extrapolating experimental data for particle transport to ITER for inductive (400 s), hybrid (1000 s) and steady state (3000 s) operation [8]. Core fuelling is provided by pellets, $S_{DT,pel}$ and by recycled particles from the edge, $S_{DT,edge}$: $S_{DT,core} = S_{DT,pel} + S_{DT,edge}$. For the case when all the particles injected from the LFS are removed by the drift, the resulting core fuelling due to the pellet injection can be expressed as: $S_{DT,pel} = C_{ext} N_{pel,HFS} f_{HFS} - N_{plasm} (\Delta W_{ELM}/W_{ped})$ f. According to predictions [9] in the range of the total DT throughput, $S_{DT,tot}$ < 200 Pa m^3 /s the fuelling from the edge saturates at a level $S_{DT,edge}$ ~ 16 Pa·m^3/s. The HFS pellet injection frequency required to keep the plasma density at a given level, N_{plasm}, for any particle transport model ($S_{DT,core}$) can be easily derived from the following expression:

$$S_{DT,core} = C_{ext} N_{pel,HFS} f_{HFS} + S_{DT,edge} - N_{plasm} (\Delta W_{ELM}/W_{ped}) f, \quad (1)$$

where f, ΔW_{ELM} and $N_{pel,HFS}$ are determined by the ELM pace making requirements. The total DT throughput can be expressed as:

$$S_{DT,tot} = N_{pel,LFS} (f - f_{HFS}) + N_{pel,HFS} f_{HFS} + S_{puff}, \quad (2)$$

where $N_{pel,LFS}$ is determined by the ELM pace making requirements, f_{HFS} is determined by Eq. (1) and gas puffing, and S_{puff} can be added to balance the D/T ratio in the plasma if necessary. The minimum DT throughput corresponds to the injection of DT pellets with equal content of deuterium and tritium and S_{puff} =0. The required tritium production can be estimated as $S_T \sim 0.5S_{DT,tot}$, although the pace making pellets and S_{puff} could contain much lower tritium fractions if they do not strongly impact the core fuel mix. Total particle throughput is displayed as a function of the required core fuelling, $S_{DT,core}$, in figures 5 and 6 for different densities $n_{DT} = 0.4 – 1\ 10^{20}m^{-3}$, different LFS pellet velocities $v_{p,LFS}$ = 500 m/s and $v_{p,LFS}$ = 1000 m/s for frequencies required for tolerable ELM pace making, f = 20 – 40 Hz. Ranges of the required core fuelling for inductive, hybrid and steady-state reference scenarios are shown in the figures by horizontal colour stripes.

Conclusion

There is a clear trade-off between the desirable ELM size, the speed of the pellets used for ELM triggering, and the DT throughput, $S_{DT,tot}$ in the fuelling system. In order to make 40 Hz injection compatible with the new throughput limitation, it would be necessary to increase the pellet velocity to $v_{p,LFS}$ ~1000 m/s, provided that the required core fuelling is ~ 100 Pa·m^3/s. For more accurate assessment further R&D is required for pedestal width and height predictions and understanding the conditions of the ELM triggering by pellets.

This report was prepared as an account of work by or for the ITER Organisation. The Members of the Organisation are the People's Republic of China, the European Atomic Energy Community, the Republic of India, Japan, the Republic of Korea, the Russian Federation, and the United States of America. The views and opinions expressed herein do not necessarily reflect those of the Members or any agency thereof. Dissemination of the information in this paper is governed by the applicable terms of the ITER Joint Implementation Agreement.

References

[1] A.R. Polevoi et al, Nucl. Fusion **43**, 1072 (2003).

[2] A.R. Polevoi et al, P1.142 in Proc. 34th EPS Conf. on Plasma Physics, Warsaw, Poland, July 2-6, 2007.

[3] P.T. Lang et al, Nucl. Fusion **45**, 502 (2005).

[4] A. Hermann, Plasma Phys. Contr. Fusion **44**, 883 (2002).

[5] S.K. Combs, A.E. Griffith A and C.R. Foust, Rev. Sci. Instrum. **72**, 273 (2001).

[6] A. Zhitlukhin et al, Journal of Nucl. Materials **363–365**, 301–307 (2007).

[7] T. Eich et al, Journal of Nucl. Materials **363-365**, 989 (2007).

[8] A.R. Polevoi et al, Nucl. Fusion **45**, 1451 (2005).

[9] A.S. Kukushkin and H.D. Pacher, Plasma Phys. Control. Fusion **44**, 931 (2002).

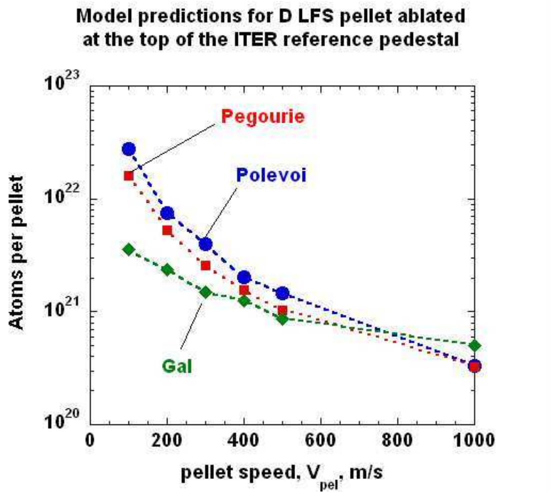

Figure 1.

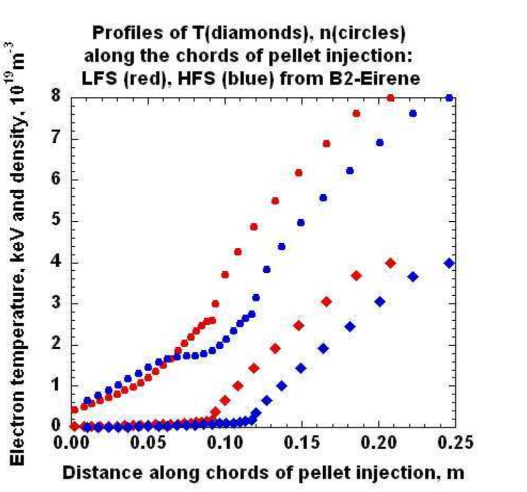

Figure 2.

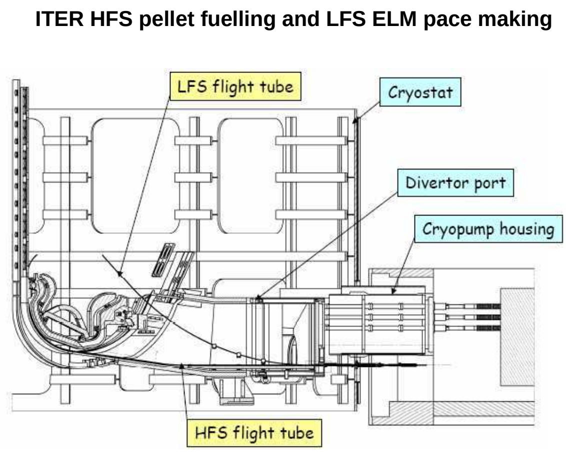

Figure 3.

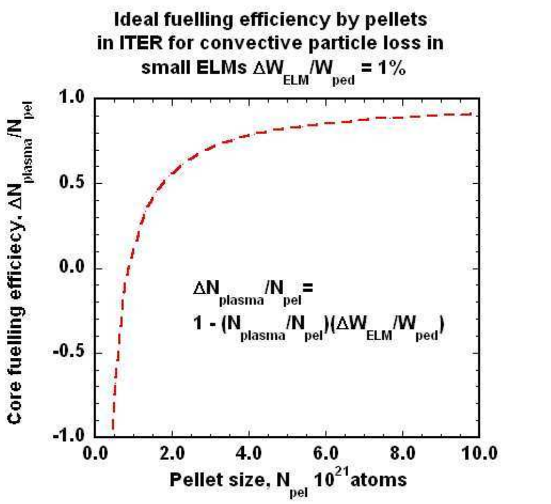

Figure 4.

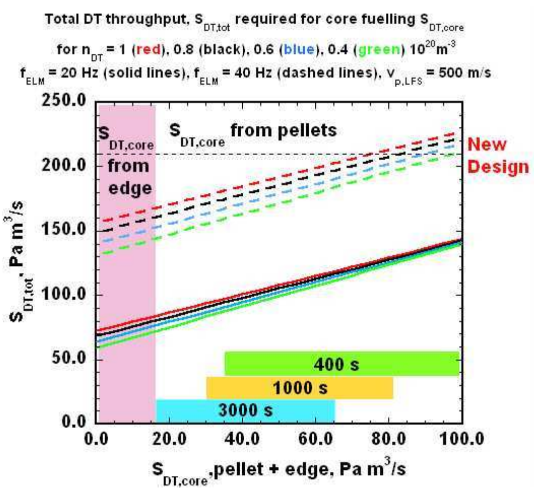

Figure 5.

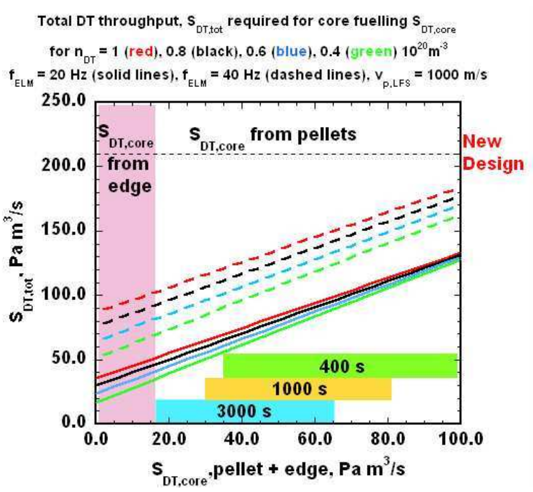

Figure 6.