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Pellet injection experiments in LHD

Gas puff fueling is widely used to build up and sustain plasma density. However, the fueling efficiency of gas puffing is low in large-scale, high-temperature plasmas since the neutral gas from gas puffing is ionized at the plasma surface. This problem occurs in the Large Helical Device (LHD) because the core plasma is surrounded by a thick ergodic layer that connects to the divertor.

Injection of hydrogen ice pellets is an important technique for core plasma fueling. A fueling pellet injector [1, 2] with five independent barrels has been designed, built, and installed on LHD. Figure 1 shows a schematic drawing of the pellet injector and the plasma vacuum vessel of LHD. The pellet injector uses a pneumatic pipe-gun type barrel; therefore high-pressure helium gas is employed for pellet acceleration. In order to prevent helium gas flow into LHD plasma vacuum vessel, double expansion chambers with large-capacity vacuum pumps and fast shutter valves were installed.

The cylindrical pellets are 3 mm in diameter and 3 mm long and have a speed of 1 km/s. A pellet contains 1×10^{21} hydrogen atoms. Pellets are injected from the outer side at the equator of LHD, and the trajectory passes through the center of the plasma. Pellet mass is measured with a microwave cavity mass detector, and pellet velocity is measured by a time-of-flight method. Injected pellets are checked by shadow graphs, which are created using a flash lamp (70 ns) and a charge-coupled device (CCD) camera, at the exit from the injector. Pellet ablation and penetration are measured by a photodiode (500-kHz sampling) and by a CCD camera with an H_α filter. Both of these diagnostics use a 33-ms exposure time. Line-averaged electron densities are measured by a 13-chord vertical-view far-infrared (FIR) laser interferometer that was installed 166° away in toroidal angle, from the pellet injection port.

Waveforms for a typical discharge with pellet injection (#15440, $B_t = 2.75$ T, $R_{ax} = 3.6$ m, $P_{NBI} = 4$ MW) are shown in Fig. 2. Pellet injection is carried out at 0.8, 0.88, 0.96, 1.04, and 1.12 s. The line-averaged electron density $\bar{n}_e$ increases sharply at the time of injection, causing the rate of increase in the stored energy, W_p, to increase sharply. Figure 3 shows the dependence of the plasma stored energy on the line-averaged electron density. At the times of injection, each pellet ablates adiabatically, thereby increasing the density without changing the stored energy; then the stored energy increases along with the recovery of electron temperature. Although the density profile is typically hollow immediately after pellet ablation, it becomes peaked during the density decay phase. The peaking factor, defined by $n_e(0)/\langle n_e \rangle$, is increased to 2 after pellet injection, which suggests improved particle confinement or generation of an inward pinch.

Figure 4 shows the maximum stored energy vs the density when the stored energy achieved its maximum. Open circles are for cases with gas puffing, and closed circles are for cases with pellet injection. The dashed lines indicate $n_e^{0.51}$, namely the prediction from ISS95 scaling [3]. In

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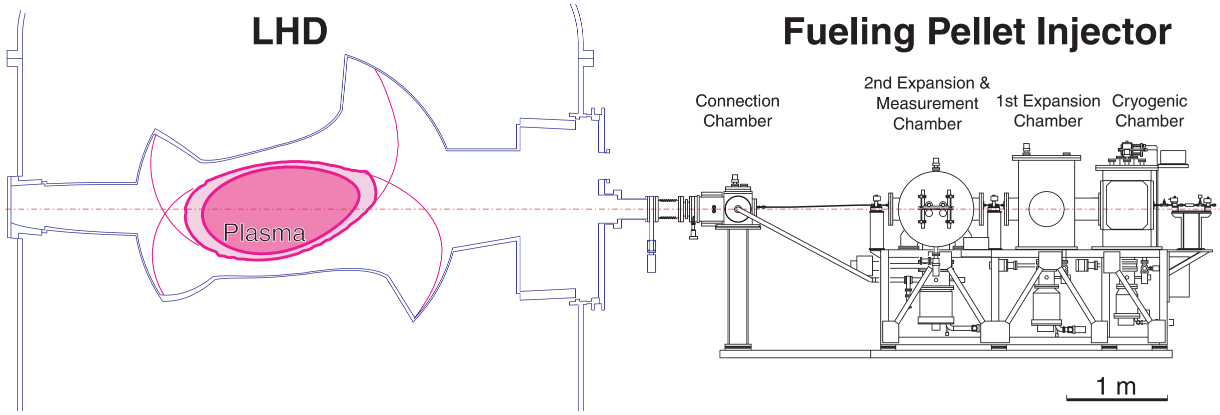

Fig. 1. Schematic drawing of the pellet injector and plasma vacuum vessel of LHD.

the case of gas puffing, the maximum density is 0.5×10^{20} m^{-3} and confinement deterioration is observed at densities above 0.35×10^{20} m^{-3}. In the case of pellet injection, there is no confinement deterioration up to 0.7×10^{20} m^{-3}, and the stored energy reaches 0.875 MJ. The maximum density achieved was 1.1×10^{20} m^{-3}. However, the stored energy is saturated at densities above 0.8×10^{20} m^{-3} for lack of heating power.

Figure 5 shows a CCD image of H_α light emission from an ablating pellet in the LHD plasma. The pellet is injected from the left side in the image. The light that expands in the vertical direction is emission from the divertor region. Since the exposure time is longer than the time necessary for the ablation (<1 ms, Fig. 6), the penetration depth of the pellet can be evaluated by the H_α light trace. The penetration depth is greater than the value estimated from the Abel-inverted density profile, which is measured using a 13-chord interferometer. An outward redistribution of pellet mass on a fast time scale is suggested.

Figure 6 shows the temporal evolution of H_α light emission from the ablating pellets and the line density measured by the FIR laser interferometer. For reference, the calculated $\iota/2\pi$ at the (moving) pellet position is plotted. Spikes observed in the H_α light emission seem to correlate with fluctuations in density. Because the temporal behavior of the density on this time scale (about 50 ms) cannot be explained by ordinary radial diffusion, it is presumed that localized dense plasma crossed a chord of the interferometer. Therefore, this dynamical process should be investigated to examine the possibility of formation of a high-

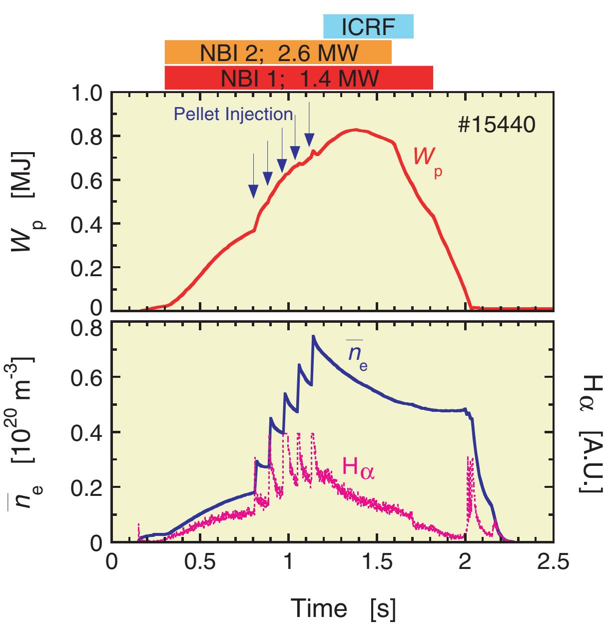

Fig. 2. Time evolution of the plasma stored energy and line-averaged density. Pellet injection is carried out at 0.8, 0.88, 0.96, 1.04, and 1.12 s. The H_α response to the pellets is also shown.

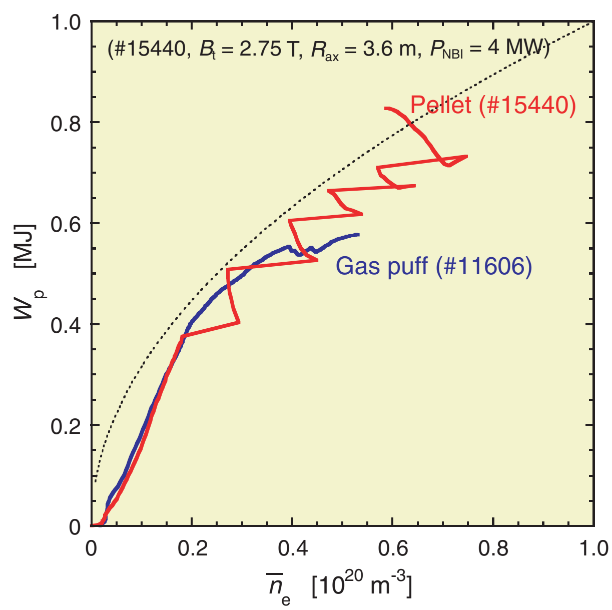

Fig. 3. W_p vs n_e. Blue and red lines indicate strong gas puffing and pellet injection, respectively.

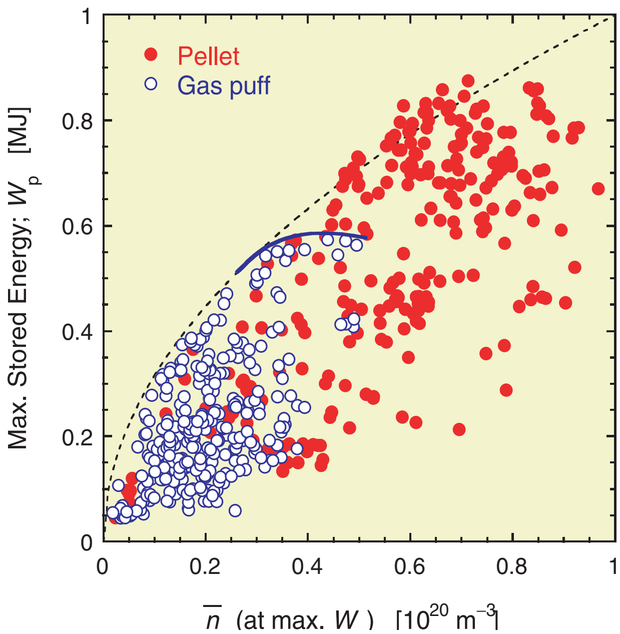

Fig. 4. Maximum stored energy vs density. The open circle symbol is for gas puffing and the closed circle symbol is for pellet injection.

density helical filament that spreads along the rational surface.

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References

[1] H. Yamada et al., Fusion Eng. and Des. (to be published).

[2] K. Kawahata, K. Tanaka, Y. Ito, A. Ejiri, and S. Okajima, Rev. Sci. Instrum. **70** (1999) 707.

[3] U. Stroth et al., Nucl. Fusion **36** (1996) 1063.

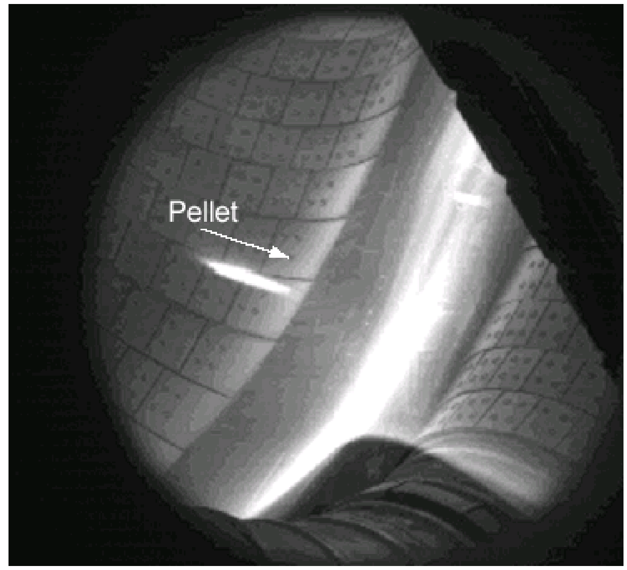

Fig. 5. CCD image of H_α light emission from an ablating pellet in LHD.

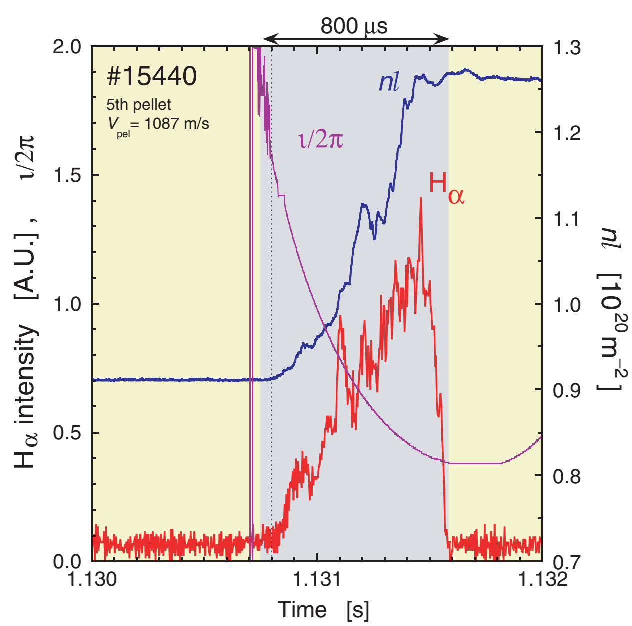

Fig. 6. Temporal evolution of H_α light emission from ablating pellets and the line density as measured by the FIR laser interferometer.

TJ-K: The German reincarnation of the Spanish torsatron TJ-I U

The former Spanish torsatron TJ-I U (R = 0.6 m, $\langle a \rangle$ = 0.10 m) has been recently transferred to the University of Kiel, Germany, in the framework of a collaboration agreement signed between the Centre de Investigaciones Energéticas, Medioambientales, y Tecnológicas (CIEMAT), Madrid, and the Max Planck Institut für Plasmaphysik (IPP), Garching. It has been installed in the Experimental and Applied Physics Department, under the oversight of Prof. U. Stroth.

TJ-I U had its first plasma in Madrid in April 1994 and was operated at CIEMAT for three years, until April 1997, a few months before TJ-II entered into operation.

TJ-I U arrived in Kiel on 10 November 1999. It was put on rollers and pulled into the experimental hall (see Fig. 1). This hall was built in the 1970s by Lochte-Holtgreve to host fusion experiments with exploding liquid wires, but it was never used for this purpose. Now, 30 years later, the hall will finally be used for fusion-related research.

To distinguish the second life of TJ-I U from its first one, it was renamed TJ-K, K standing for Kiel. TJ-K will be mainly operated by students. The magnetic configuration will remain unchanged. Because of the limitations of the power supply (1 kA at 1 kV steady state), the envisaged plasma parameters will be significantly lower than those achieved at CIEMAT (see Table 1). The maximum field will be 0.2 T. At this field, the discharge duration will be limited by cooling of the coils to 1 min. At 0.1 T with an inward-shifted configuration, discharges with a duration of of 10 min will be possible.

Table 1. Maximum plasma parameters and discharge duration τ achieved in TJ-I U and projected in TJ-K

	TJ-I	TJ-K
B, T	0.67	0.2
P, kW	300	3
$n_e(0)$, m^{-3}	6×10^{18}	1×10^{18}
$T_e(0)$, eV	200	10
$T_i(0)$, eV	70	1
τ	30 ms	5 min

A helicon antenna will be installed as the initial heating system in TJ-K. The heating power will be 5 kW at variable frequencies in the range of 10 MHz. Hence the plasma parameters will be limited by losses due to the ionization of neutrals. The electron temperature will probably stay below 10 eV, and for a fully ionized plasma at n_e = 1×10^{18} m^{-3} the temperature will be still lower.

Although the TJ-K plasma parameters are different from those of fusion plasmas, the dimensionless parameters that govern the physics in turbulence simulation codes are comparable. Hence, the results can also help to test models developed for fusion plasmas.

We will take advantage of the lower temperature to use Langmuir probes, which allow good temporal and spatial resolution, for fluctuation measurements. The measurements will serve to investigate both the microscopic topology and statistical properties of the plasma turbulence. The experimental investigation is backed by turbulence simulations using the three-dimensional (3-D) drift Alfvén code of Bruce Scott (IPP Garching). Realistic 3-D geometry for TJ-K, based on the work of Alexander Kendl (IPP Garching), will be used. The goal is a close comparison of experimental and numerical fluctuation data, which will be analyzed with the same software tools. We will investigate the importance of Alfvén dynamics for the drift-wave instability, the importance of local magnetic shear and curvature, the existence of zonal flows, and the signatures of self-organized criticality. Measurements can be carried out on open field lines in the scrape-off layer and on closed ones in the confinement zone. The flexibility of the mag-

Fig. 1. The TJ-K torsatron in the experimental hall at Kiel University.

netic configuration of TJ-K will help to disentangle the influences of shear and curvature on turbulence.

It is planned to have a first helicon plasma in early 2000. Poloidal Langmuir arrays should be available some months later to measure k-ω spectra and related quantities. To gain even more flexibility in the plasma parameters, additional electron cyclotron resonance heating (ECRH) at 2.54 GHz is envisaged for the future, as is the development of methods to influence turbulence, such as biasing or active feedback with electrodes.

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