(3) RF Heating Technologies

In the experimental campaign of 2008FY, EC heating have made steady progress for high power and long pulse operations. ICRF antennas are removed from LHD and have been modified for future high power heating and/or upgraded to high k-parallel wave excitation.

The most remarkable result of EC heating was the extension of the long pulse operation in the high power region exceeding 1 MW using both ECH and NBI. In 2005FY we achieved the record of 1.6 GJ for input energy, the highest value in the world magnetic fusion devices, with the average input power of 490 kW (ICRF: 380kW, ECH: 110kW).

The main target in the steady state operation in 2008FY was to achieve as long pulse sustainment as possible with the input power of more than 1 MW. It was a first long pulse trial using 77 GHz gyrotrons.

At the long pulse operation, impurity influx of metal dusts or flakes from the wall or divertor tiles has been a major factor of plasma. Especially in the higher power operation of more than one mega watt, the impurity influx frequently caused bright sparks. After the bright sparks, plasma was usually terminated by radiation collapse. In the last year campaign, the long pulse discharge by mega watt power injection was an important task in LHD. Because the high power can sustain high density plasmas and it improves the plasma parameters such as temperature and confinement time. A plasma sustainment with the injection power of more than 1.0 MW (0.51MW ECH and 0.5MW NBI) and 93 seconds was successfully achieved. The pulse length was limited by the out-gassing inside one of the 77 GHz gyrotrons. These gyrotrons might need more conditioning.

Parallel operations of the two high power 77 GHz gyrotrons were enabled before the experimental campaign. Evacuation and enforcement of the cooling of the waveguide transmission line were completed for these two high power/ long pulse 77 GHz system.

ECH In 2008FY, a new 77 GHz gyrotron developed under the collaboration between NIFS and University of Tsukuba was installed in one of the gyrotron tank as a replacement of an old 168 GHz gyrotron. The specified power and pulse width were 1.2 MW/5s and 0.3MW/CW. This new gyrotron was brought to NIFS after successful demonstration at the short pulse, 1 MW operation in University of Tsukuba. In addition to this new gyrotron, a previous 77GHz gyrotron, that had been operated in 2007FY and damaged at the diamond window, came back from the repair. The conditioning of these gyrotrons was continued injecting the power into the dummy load. During the experimental campaign, the output power from those gyrotrons was coupled to the evacuated 88.9 mm corrugated waveguide system to transmit the power into LHD. Final achievement of these gyrotron in 2008FY was 1.01MW/3.3s and 1.02MW/5.0s kW at high power operation mode, and 0.29MW/60s and 0.24MW/220s at long pulse operation.

The waveguide system used for this gyrotron was modified in accordance with this upgrade of the gyrotron. Similar upgrades, the change of O-ring vacuum seals at the miter to metal gasket, installation of copper plates with water cooling channel covering the waveguide surfaces all along the transmission line were executed on one more transmission line. Some of the miter bends are developed and fabricated in NIFS to add the cooling channels in the miter bend block and to be accommodated with the use of metal gasket. The vacuum window at the LHD antenna is also replaced by that of the CVD diamond for the higher power and longer pulse transmission capability. Mirrors of one of the horizontal injection antenna systems that is newly connected to the 77 GHz gyrotron were also upgraded. These mirrors consists of a steering flat one, a strongly focusing one inside LHD vacuum vessel and three flat and one focusing additional mirrors. All those mirrors were replaced by those with water cooling channels. All inlet/outlet water channels have bellows section to allow the angle adjustments of the mirrors, as well as the steering mirror that has ±25 and ±7.5 degrees steering capability in toroidal and poloidal directions, respectively.

ICRF Present antenna design of LHD is emphasized to launch high power by keeping a large loading resistance. Single center strap type antenna is fitted to launch low k// wave number in front of the antenna which made large coupling with the plasma. In tokamaks, there are several experiences to launch low k// wave for plasma heating. From the low field side launch as usual present large devices, the heating efficiency is not good due to impurity problems. On the other hand, from the high field side launch single strap antenna has still good heating performances. Present LHD antenna design is based on this understanding. LHD antenna is partially high field side launching type.

We are now preparing two new type antennas. One is the broad antenna having a wide center strap and the other is parallel antenna having a capability of k// control. These antenna designs are next step from the present basic design. For the new antenna design, recently circulating commercial computing codes are beneficial to optimize the current distribution, suppression of high electric field localization and a pattern of electromagnetic wave emission. We used HFSS code to optimize these new antenna designs. This simulation code is also used to explain the experimental data of the past ICRF steady state experiments.

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