(3) RF Heating Technologies

In the experimental campaign of 2009FY, EC heating system has been operated with three gyrotrons of exceeding 1 MW class. Design study of new ICRF antennas are accelerated and fixed. Furthermore, the new set of antenna is fabricated for the higher power heating and/or high k-parallel wave excitation.

The most remarkable result of EC heating was the achievement of exceeding 15 keV central electron temperature at relatively low density ($3 \times 10^{18}\,m^{-3}$) plasma condition. Such achievement is enabled by the simultaneous operations of the three high power 77 GHz gyrotrons. Evacuation and enforcement of the cooling of the waveguide transmission line were completed for these three high power/long pulse 77 GHz systems.

The main target in the steady state operation in 2009FY 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 multi- 77 GHz gyrotrons. At the long pulse operation, two of the gyrotrons were suffered from pressure rise inside the tubes may be due to an excess temperature rise of the inner components heated up by a stray radiation in the tubes. On the other hand the upgraded gyrotron worked well but had an operation limit due to an excess temperature rise at a part of matching optics unit (MOU) that connect the gyrotron output to the transmission waveguide.

ECH In 2009FY, an improved 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 1.5 MW/5s, 1.2MW/10s and 0.3MW/CW. Main improvements are at magnetron injection gun to increase the oscillation efficiency and the further optimization of the output high power beam at the CVD window to reduce the stray radiation inside the gyrotron. This new gyrotron was brought to NIFS after successful demonstration at the short pulse, 1.5 MW in University of Tsukuba. In addition to this new gyrotron, two 77GHz gyrotrons, that had been operated in 2008FY were continued injecting the power into the dummy load for conditioning and both succeeded to demonstrate their full specification at the pulse mode. 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. For the pulse operation, total simultaneous injection power to the LHD exceeded 3.5MW and it is fully utilized for the exploration of high temperature plasmas, plasma confinement study, and collective Thomson scattering study.

Several transmission line components used for more than 1 MW operation are improved. The power monitor was improved to accommodate to 1MW CW operation by replacing the reflector material to copper, which has higher electrical and thermal conductivity than normally used aluminum. Development of a new waveguide switch that has water cooling capability enabled the easy transition of the operation modes between LHD injection and the gyrotron conditioning.

ICRF Newly designed ICRF antenna named HAS antenna was fabricated and ready to be installed in the LHD vacuum chamber. The coupling characteristic of present antenna is emphasized to launch high power by keeping a large loading resistance. Single current strap type antenna is fitted to launch low k// wave number in front of the antenna which should make large coupling resistance with the plasma. In tokamaks, there are several experiences to launch low k// wave for plasma heating from the low field side launch. However the heating efficiency is not good due to impurity problems. From the high field side launch, single strap antenna has still good heating performances in tokamaks. Present LHD antenna design launching from outboard side is based on this understanding. LHD antenna is partially high field side launching type.

In former years three pairs of antenna were mounted in LHD and then dismounted to repair from the arcing problem inside the vacuum chamber in 2008. In 2010, newly designed HAS antenna will be installed. HAS antenna is also single strap antenna, but each antenna loop installed from the up and the bottom ports are positioned almost parallel near the equatorial plane. This antenna configuration makes it possible to launch electromagnetic wave field with roughly controlled wave length along the magnetic field by changing the phases of each strap currents.

For the antenna design and analysis of the experimental results, commercial computing codes are used to calculate and optimize the current distribution, suppression of high electric field localization and a pattern of electromagnetic wave emission. We used HFSS code to optimize the HAS antenna design. This simulation code is also used to explain the experimental data of the past ICRF steady state experiments.

The impedance matching network of new antenna system is analyzed to control the current phase between two antenna loops with keeping the impedance matching conditions. The two antenna loops are strongly coupled and separately connected to transmitters through liquid impedance tuners which maximum standing voltage is limited.

We have been developed and operated six RF transmitters having 1.5 MW output power capability using high power tetrode of CPI or of Thales companies. For the ITER ICRF hardware system design, we collaborated with ITER ICRF team to test the ability of the high power tetrode at the working frequency of 65 MHz which is ICRF heating frequency of ITER.

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