§8. Plasma Startup by NBI

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The standard plasma producing scenario in helical system is to initiate plasma by ECH and additionally heat it by NBI. This scenario works very well and so in LHD. In the second campaign, we have succeeded to produce high pressure plasma by this method. However, there is a big constraint in this scenario that we cannot change the magnetic field strength far apart from electron cyclotron resonance condition for ECH gyrotron frequencies. This situation makes it difficult to study magnetic field dependence especially high beta research.

Because plasma is sustained by NBI alone in most discharges, and heating mechanism of NBI is not affected much by magnetic field strength, it is happy if we can initiate plasma by NBI, too. We have tried it and succeeded initiating plasma by NBI. Figure 1 shows time evolution of plasma density and stored energy in NBI discharge. Upper graph shows the discharge where the plasma was initiated and built up by NBI alone. The case of standard ECH initiated discharge is shown in lower graph for comparison. Experimental conditions were the same in both discharges except for the gas puff program. Only co-injection beam was used, and injected port through power was 1.6 MW. We can see that the achieved density and stored energy are the same for both cases.

In the case of NB startup, beam was kept injecting for 0.4 second before gas puff. During the period, low density plasma of 1x10^{18} m^{-3} appears, which is considered to be produced by ionizing background gas flown from the neutral beam line. Judging from the fact that the line emissions of carbon III began to be detected at t = 0.6s and oxygen V at 0.7s, electron temperature also increases. It is after this point that gas puff is effective for building up density. As can be seen from the figure, a target plasma of 1x10^{19} m^{-3} was generated by the first gas puff, which is the same density that the ECH produces. Then the situation is the same as the standard scenario. By adding the second gas puff, we can increase the density and heat the plasma. In spite of rather long full shine through period before plasma buildup, no deterioration due to carbon influx from beam armor plates was observed. The radiation powers are similar for both discharges in Fig. 1.

In this process, it seems necessary that a thin hot plasma exists before gas puff for the NB startup. This plasma can be produced by ionization of background hydrogen gas by high energy ions. The vacuum pressure in the vacuum vessel was 10^{-3} Pa before beam injection. About 2% of the beam can be ionized and confined. These high energy ions are lost by charge exchange, and steady state is achieved within 1 ms. The average density of high energy ions is estimated to be 5x10^{13} m^{-3}, and ionization rate of background gas by these fast ions is about 10^{18} m^{-3}/s which is consistent with the experimental results.

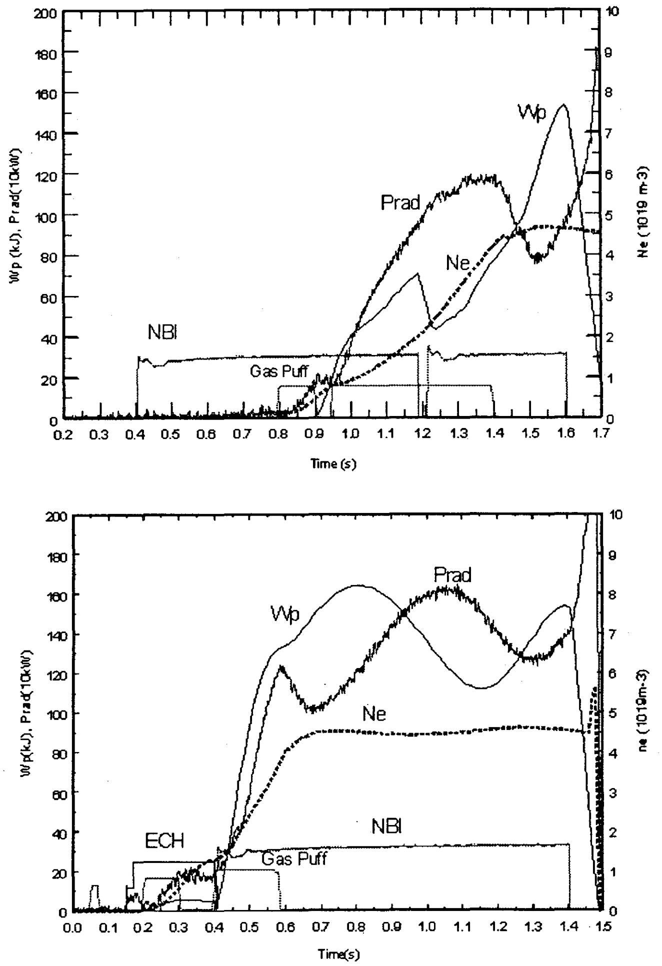

Fig. 1 Comparison of plasma startup by NBI with a standard ECH initiated case.

Although we found that this method worked well in LHD, we didn't have enough time to optimize the technique yet. For example, optimum initial gas pressure to minimize the pre-injection time is important for decreasing the heat load on the beam armor plates. It is also interesting to know whether counter injection is effective under low magnetic field strength, which is related to the confinement of fast ions. These are the topics that will be studied in the next experimental campaign.