High-Power Injection with Negative-Ion-Based Neutral Beam Injectors in Large Helical Device

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A negative-ion-based neutral beam injection (NBI) system started its operation in 1998 with two injectors in the Large Helical Device (LHD), which is the world-largest superconducting helical system, and the third injector was operational in 2001. The LHD negative-NBI system is arranged tangentially in which one injector has the opposite injection direction to the other two injectors, and is characterized by a main heating device, in contrast with the JT-60U one for the current drive. The injection species is hydrogen, and the nominal injection energy and power are 180keV and 5MW, respectively, for one injector. The total injection power achieved is 13MW, and one injector that is equipped with modified ion sources with multi-slotted grounded grid has achieved 184keV–5.7MW injection. Reliable injection of around 10MW for 2–3 sec is usually made for plasma experiments every 3min.

Two large negative-ion sources are installed in one injector. The ion sources, the grid area of which is 25cm x 125cm segmented into five parts, are cesium-seeded volume production ones, and were developed based on the R&D preceding the construction of the injectors. The ion sources, however, are still under development and improved year by year. Especially, modification of the single-stage accelerator including a change to the multi-slotted grounded grid from the multi-round one has led to a drastic increase in the injection energy and power. Since the transparency is much higher in the multi-slotted grounded grid, the gas pressure is lower in the acceleration gap. Then, heat load of the grounded grid is reduced due to a reduction of both the stripping loss of the negative ions and the direct intersection of the accelerated negative ions and electrons. As a result, the beam-acceleration voltage is increased above 180kV in a short conditioning period of around one week without serious breakdown. The arc power supply is divided into twelve circuits, each of which is connected to an electrically insulated filament power supply. Individual control of both the arc and the filament voltages is effective to uniform beam production from a slender arc chamber of 35cm x 145cm. Control of the plasma grid temperature is also important to efficient negative ion production and the beam uniformity.

Long-pulse injection has been performed with a reduced power. Using one ion source, a continuous injection for 120sec was achieved with an injection power of 0.2–0.3 MW. The beamline components are actively water-cooled, except for molybdenum protection plates for the injection porthole, which would limit the injection duration to a few minutes. The control of the plasma grid temperature in the ion source is a key issue for the long-pulse operation.

The injection performance of the LHD negative-NBI, including the high-power ion sources, the long-pulse operation, and the beam uniformity, are presented in detail.