Novel method developed in the National Spherical Torus Experiment for generating the plasma current in tokamaks

A new method of plasma generation in tokamaks called Coaxial Helicity Injection (CHI) has been successfully applied in the National Spherical Torus Experiment (NSTX) fusion experiment at the Princeton Plasma Physics Laboratory. Utilization of the CHI technique could lead to smaller, more economical fusion power plants.

While the CHI method has previously been studied in smaller experiments, such as the Helicity Injected Tokamak (HIT-II) at the University of Washington, the results from the much larger NSTX, demonstrate the exciting potential of this method.

Until now, almost all tokamak plasma confinement devices have relied on a solenoid through the center of the device to induce the plasma current needed for confinement. The spherical torus is a specialized form of the tokamak in which the hole through the center of the doughnut-shaped plasma is made very small. This saves space and allows the externally produced magnetic field to be utilized much more efficiently than in a conventional tokamak. However, little room is left for a solenoid, so future reactors based on the spherical torus will require an alternate method for starting the plasma current.

The generation of the plasma current by CHI involves a process called magnetic reconnection, which is also involved in the eruption of solar flares on the surface of the sun. This process of reconnection has been experimentally controlled in NSTX to allow this potentially unstable phenomenon to reorganize the magnetic field lines to form closed, nested magnetic surfaces in the shape of a doughnut carrying a plasma current up to 160,000 Ampères. This is a world record for non-inductive closed-flux current generation, and demonstrates the high current capability of this method.

An invited talk to be presented at the 48th Annual Meeting of the APS Division of Plasma Physics in Philadelphia [paper BI1-2] will describe how this process is used to generate the initial plasma current without using a solenoid.

Detailed Information

The process of CHI in NSTX and some results obtained during the recent experiments are illustrated in Figure 1. To generate plasma current by this method, a special combination of poloidal and toroidal magnetic fields is initially produced using conventional magnetic coils located outside the NSTX vacuum vessel. After puffing a small amount of deuterium gas into the vacuum vessel, a voltage of up 2000 Volts is then applied between insulated coaxial electrodes in the bottom of the vacuum vessel. The gas breaks down into a plasma and begins to conduct electrical current along the magnetic field lines joining the electrodes. This causes the magnetic field lines to stretch, carrying an expanding bubble of plasma into the vacuum chamber. When this plasma fills the chamber, the injected current is rapidly decreased, causing the magnetic field lines to disconnect from the external coils and reconnect to form the closed field line configuration. In NSTX all of this happens within 5 milliseconds. It is particularly important that in the recent NSTX experiments, the ratio of the toroidal plasma current obtained to the current injected by the electrodes exceeded 60. Comparison with the earlier results from the HIT experiment, suggests that even higher current multiplication can be obtained in future larger spherical torus devices. The method is also applicable to tokamaks and could be used to simplify the design of a future fusion reactor.

CHI research on NSTX is a collaboration between researchers from the University of Washington and Princeton Plasma Physics Laboratory. This work is supported by US Department of Energy contracts DE-FG03-96ER5436, DE-FG03-99ER54519 and DE-AC02-76CH03073.

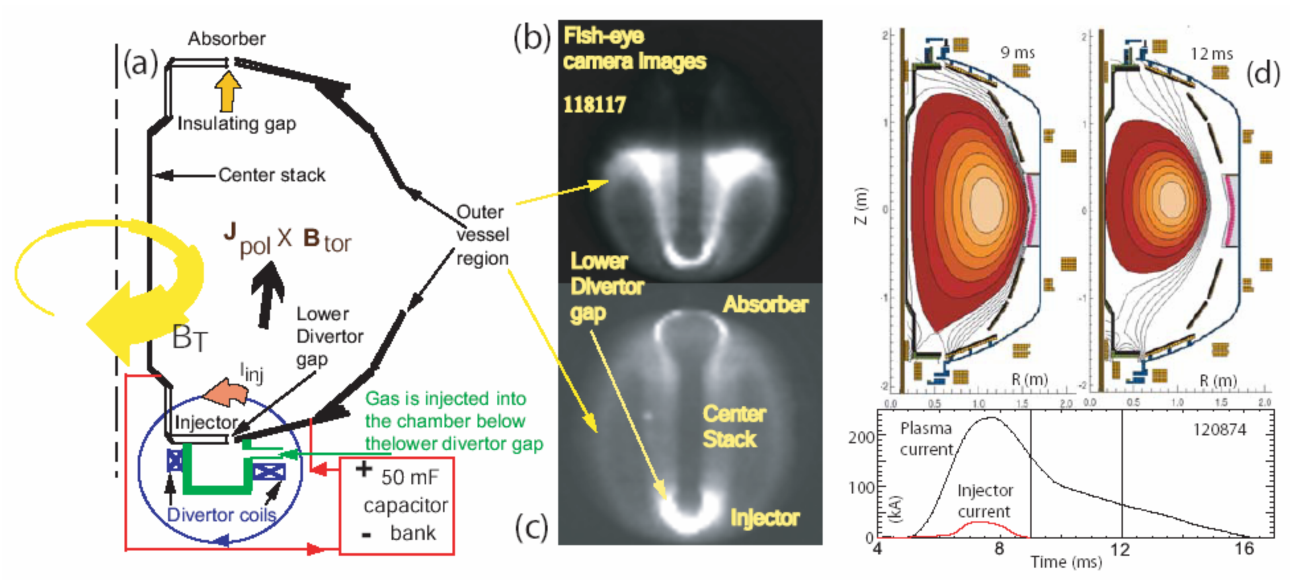

Figure 1 (a) shows the machine components used for CHI startup in NSTX. The NSTX vacuum vessel has a major radius of 0.85m and a volume of 30 cubic meters. It is fitted with ceramic rings at the top and bottom so that the central column and the inner divertor plates are electrically insulated from the outer divertor plates and the outer vessel components. In (b) fast camera fish-eye image early in the CHI pulse shows the plasma expanding upwards from the injector. The upper bright region in (b) is the top of the CHI plasma that has reached the middle of the vessel. At this time, the plasma current is below the peak value. As the plasma current increases to its peak value, the discharge further expands vertically to fill the vessel, as shown in (c). In (d), analyses of the magnetic structure after the injector current has decayed to zero, show the shape evolution of the CHI produced plasma, which has now become decoupled from the injector.

The fish-eye images recorded by a fast camera were taken by Dr. Ricardo Maqueda of Nova Photonics. The equilibrium reconstructions were from the LRDFIT Grad-Shafranov equilibrium code developed by Dr. Jon Menard (PPPL).