A Process Similar to the Eruption of Solar Flares has been Successfully Controlled for Generating High-Quality Plasma Configuration in the National Spherical Torus Experiment

This method known as Coaxial Helicity Injection (CHI) could eliminate an expensive component in tokamaks, leading to a more economical fusion reactor

CHICAGO, Illinois, Nov. 8, 2010 – Researchers at the Princeton Plasma Physics Laboratory have successfully used Coaxial Helicity Injection (CHI) to generate plasma current and couple it to a conventional current generation method at the National Spherical Torus Experiment (NSTX) fusion experiment. After coupling, the combined process generated 1 million amperes of current using less energy than needed to generate this current using the conventional means by itself, thus demonstrating that a high-quality initial magnetic configuration was produced by CHI. The CHI method has been studied in the smaller Helicity Injected Tokamak (HIT-II) at the University of Washington. NSTX is thirty times larger in volume, and researchers have found the process to be much more efficient on the machine, indicating that it scales well to future larger machines.

Plasma confinement devices based on the tokamak concept rely on a solenoid through the center of the device to generate the initial current. Because the solenoid is used as an electrical transformer, its pulse length is limited in duration and cannot sustain the initial current indefinitely in a steady-state tokamak. Thus a method to eliminate the solenoid would remove a large component from the center of the tokamak, making the device simpler and less expensive. This allows the freed space in the center to be used in optimizing the device, making the tokamak more efficient by producing a magnetic configuration similar to that in a spherical tokamak.

CHI generates plasma currents by producing a magnetic bubble using magnetic reconnection. This is analogous to producing a soap bubble by blowing air through a ring dipped in soap solution. During CHI, currents are driven along magnetic filaments so that the resulting magnetic forces overcome the magnetic field line tension and cause the magnetic surface to stretch into the tokamak vessel. The figure below shows a sequence of camera images that shows the bubble being generated on the lower part of NSTX and expanding to fill the entire vessel volume. Solar flares on the surface of the sun erupt and reconnect through the process of magnetic reconnection.

After this bubble has been created in NSTX, it carries a current of more than 250,000 amperes. As the current in the bubble begins to decay the solenoid is energized and used to increase this current to 1 million amperes. The plasma quality produced by this new method is compatible with the current generation method that has been used in tokomaks, allowing for the possibility of eventually eliminating the solenoid. In a steady-state reactor this initial current would be sustained by injecting high-energy particles. These particles would produce more current if the plasma density is small. For easier control of high-performance plasma, it is necessary that the distribution of the plasma current is preferentially driven near the outer edges of the magnetic configuration. In addition to CHI producing a high-quality current, the resulting current profile and the plasma density are what are needed for high-performance steady-state discharges. These important new results, combined with the capability of CHI to produce a large amount of current at high efficiency in larger machines, bodes well for the application of this new method in future tokamaks and spherical tokamaks.

Detailed Information

The process of CHI in NSTX and a summary of recent results 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 to 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 recent NSTX experiments, the ratio of the toroidal plasma current obtained to the current injected by the electrodes has approached 100. The current is generated at high efficiency of 10 Amp/Joule of stored capacitor bank energy. Comparison with the earlier results from the HIT experiment suggests that even higher current multiplication can be obtained in future larger spherical torus devices. When the decaying CHI plasma, which have produced record startup currents of over 300kA is coupled to induction, the current increases to over 1MA using 75precent of the magnetic flux stored in the central solenoid. This is much more current than what is produced by induction alone using the same amount of flux.

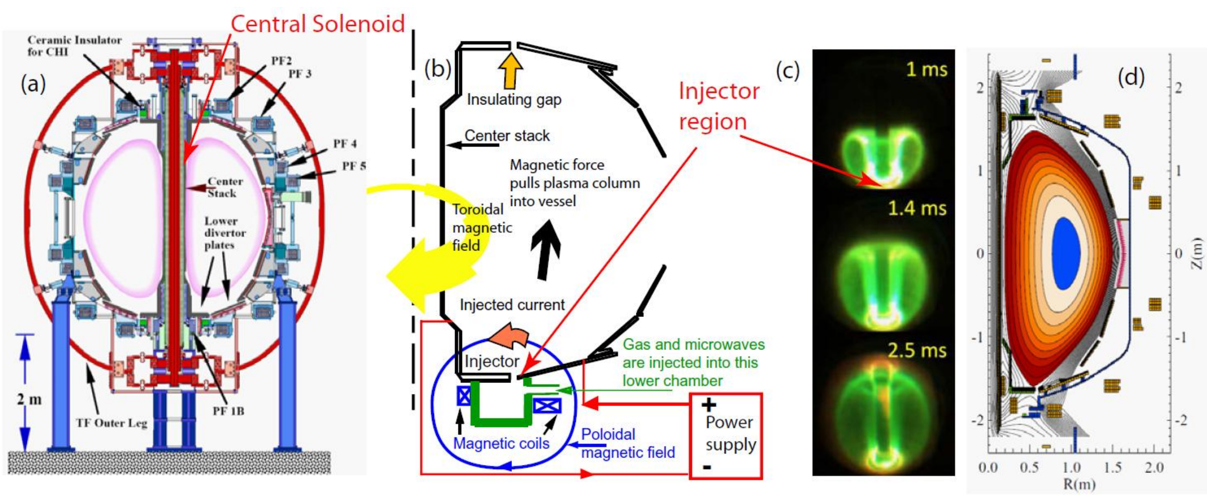

Figure 1: (a) NSTX machine layout showing the toroidal field coil in red and the poloidal field coils (labeled PF1 to 5), (b) simplified CHI schematic, (c) sequence of fast camera images of a CHI discharge inside NSTX. The top image shows the expansion of the CHI discharge one

thousands of a second after the CHI discharge is initiated. As shown in the third frame, within three thousands of a second the plasma has fully filled the vessel and (d) magnetic reconstructions of a discharge soon after being driven by the central solenoid shows a highly elongated plasma. Other detailed measurements (not shown here) show the current distribution of the plasma to be preferentially driven near the outer edges of the magnetic configuration as required for a high-performance plasma.

CHI research on NSTX is a collaboration between researchers from the University of Washington and the Princeton Plasma Physics Laboratory. This work is supported by US Department of Energy contracts DE-FG02-99ER54519 AM08 and DE-AC02-09CH11466

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Abstract: DI3.00004

Demonstration of Inductive Flux Saving by Transient CHI on NSTX

Invited Session DI3: Alternate Configurations and Startup
3:00 PM–5:00 PM Monday, November 8, 2010
Hyatt Regency Chicago - Grand Ballroom EF