

Self Generated “Bootstrap” Current Contains Magnetic Fusion Plasma

The tokamak is a toroidal magnet configuration used to confine plasmas for the development of fusion energy. It relies on the magnetic field produced by a toroidal current flowing in the plasma for confinement of particles and heat. The most common and technically simplest method for driving the plasma current is magnetic induction. However, inductive current drive is inherently pulsed and therefore incompatible with the steady operation of a power plant, which is highly advantageous for the economy of fusion power. Other current drive methods, based on injection of a beam of energetic particle or a powerful beam of microwaves have been developed. These current drive methods are highly versatile and are compatible with the steady state operation, but are not suitable (sufficiently efficient) to drive all the current.

An entirely different approach is to take advantage of a self generated plasma current, the so called “Bootstrap Current”. The fraction of the plasmas current that can be driven by the “Bootstrap Current” increases with increasing plasma pressure. Higher plasma pressure naturally results in a higher rate of fusion power, which in turn heats the plasma to sustain the high plasma pressure. Therefore scientists try to find magnetic configurations with the highest plasma pressure for a given confining magnetic field. The greatest challenge of achieving a high bootstrap fraction plasma is to find a self consistent equilibrium such that the profile of the bootstrap current is nearly identical to current profile required to confine the plasma. A small difference between the bootstrap current and the confinement current can be driven by microwaves or energetic particle beams.

An international team of scientists working on the DIII-D national facility in San Diego are seeking to find magnetic configurations with high bootstrap fraction. In a series of recent experiments on the DIII-D tokamak they have succeeded develop plasmas with up to 80 percent of the plasma current generated internally. Figure 1 shows results from one of these experiments. After an initial period of plasma preparation using the magnetic induction, the induction system is disabled and the plasma is allowed to coast on its own for as long as the plasma heating systems are available. With appropriate initial conditions, the plasma is sustained with constant average current. The fraction of the current provided by the bootstrap effect rises to over 80% by the end of the pulse. The remainder is driven by the high energy particle beam that also heats the plasma.

When compared to high performance operation sustained with the conventional magnetic induction, using theoretical and empirical normalizing rules, these plasmas have similar normalized pressure, and similar particle and energy confinement. The toroidal current in these plasmas is still low when normalized and compared to reactor requirements. The limit to performance is a relaxation oscillation, involving improved confinement and steepening of the pressure profile at a location roughly two-thirds of the way from the plasma axis to its surface. When the pressure gradient becomes too large, an instability occurs releasing up to a quarter of the plasma energy and a tenth of the current. However, the plasma recovers and the energy and current build up again. This is a very optimistic result. If a means of controlling the steepening of the pressure profile can be devised it may be possible to raise the pressure and current to levels suitable for steady-state reactor operation.

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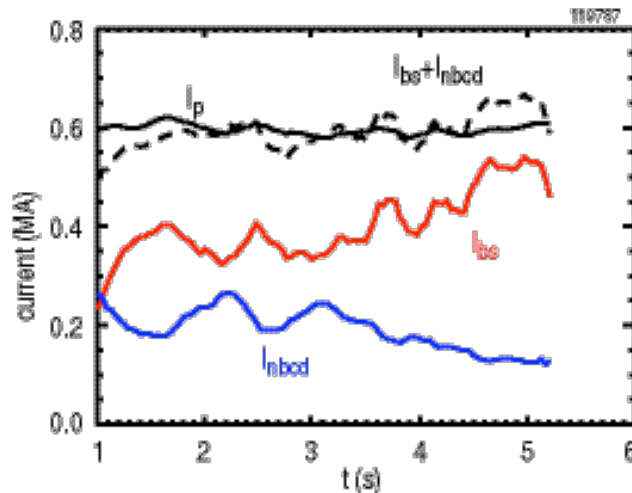


Figure 1 This plot illustrates the behavior of the toroidal plasma current in these self-consistent, noninductive plasmas. As indicated, the total current is constant at roughly 600,000 amperes. The bootstrap current rises during the pulse, exceeding 80% of the total for the last half-second or so. The current driven by the injected beam is initially about a third of the total, but falls to less than 20%. The sum of the two accounts for the entire current within the uncertainties of the measurements.