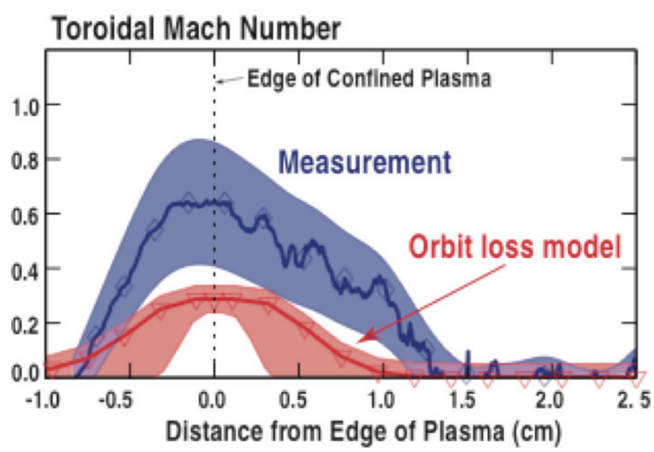
New Ways of Spinning the Plasma Offer Opportunities for Improved Fusion Performance

Many things, like Frisbees and drill bits, work better when they are spinning like a top. It has been realized in recent years that spinning the plasma results in wide-ranging benefits for magnetic fusion, including improvements in how well the plasma confines its internal energy and how high a pressure can be achieved before instabilities occur. While rapid rotation (*i.e.*, spinning) is easily driven in today's tokamaks by spinning up the plasma through the injection of high velocity neutral particles, future fusion will not need such particle injectors. Hence, it is important to learn how to achieve the rapid rotation without energetic particle injection.

Recently, scientists at DIII-D have investigated alternate means of driving plasma rotation without high velocity neutral particles that may ultimately be exploited in ITER and beyond. One intriguing option under study is that the plasma appears to be capable of generating its own rotation. This may seem to be too good to be true, as at first glance this unassisted spin-up of the plasma (dubbed "intrinsic rotation") may appear to violate a very basic law of conservation of angular momentum. However, a number of distinct mechanisms have been proposed to explain intrinsic rotation without violating angular momentum conservation, and evidence supporting a couple such mechanisms has very recently been collected on DIII-D. For example, measurements at the boundary of the plasma show a very narrow, localized region of relatively rapid rotation (see Figure). The magnitude and radial extent of this layer is qualitatively consistent with a theoretical model that considers losses of particles as a means of generating this edge layer (also shown in Figure). The basic idea of the model is that the plasma begins with an initial distribution of ions moving equally in all directions (*i.e.*, zero net rotation). However, orbit loss processes can preferentially remove a subset of the initial ions moving in one direction (*e.g.*, clockwise), therefore leaving the remaining ions with net rotation in the opposite direction (*e.g.*, counter-clockwise).



Evidence also exists that transport processes, termed "residual stress", may also lead to a spin up of the plasma. Transport is the name given to processes that move quantities across magnetic field lines. While transport from residual stress does not result in the production of net angular momentum, it can redistribute angular momentum from outside the boundary to the core of the plasma. In this way, the core can gain angular momentum in one direction at the expense of oppositely going angular momentum outside the boundary, the latter which may be damped away due to drag with neutrals. Theoretical models show that strong shear in the plasma's radial electric field is one possible mechanism of creating residual stress. Experimentally, a clear relationship between the edge pressure gradient (which is a key contributor to the radial electric field) and the torque associated with the intrinsic rotation is observed.

In addition to self-generation of plasma rotation, new methods of spinning the plasma using external means relevant to ITER have also been investigated. In particular, three-dimensional symmetry-breaking ("bumpy") fields have been utilized to spin the plasma from rest and maintain advanced operating modes with low external momentum input. Previously, a large external torque from the injection of neutral particles was required to maintain such advanced operating modes. An interesting aspect of the theory of plasma flow generation by symmetry-breaking fields has recently been tested. Specifically, the theory predicts that at low rotation velocity, the torque from these three-dimensional fields can be dramatically increased, resulting in enhanced drive to spin the plasma, as well as acting as a barrier to combat other effects that might otherwise try to slow the rotation down.

The combination of these various effects might ultimately lead to very specific tailoring of the rotation profile to target different aspects of performance dynamically in a discharge.

This work was supported by the US Department of Energy under DE-AC02-09CH11466 and DE-FC02-04ER54698.

Contacts: W.M. Solomon (858) 455-3547, solomon@fusion.gat.com
M.R. Wade, General Atomics (858) 455-4165, wade@fusion.gat.com