SPIRIT Concept and CT Research on MRX

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PPPL conceived a fusion concept developing research project called **SPIRIT [**Self-organized Plasma with Induction, Reconnection, and Injection Techniques**],** which will enable us to explore important new regimes of compact toroid (CT) plasmas. [1-3]. The main features are: (1) formation of FRC plasmas with large flux (50 mWb) by merging two spheromaks with opposite helicities; (2) flexibility to assess the stability characteristics of FRC plasmas by varying plasma shape and kinetic parameter s, by using passive stabilizers, and by injecting energetic ions; (3) sustainment of the FRC for a time significantly longer (1-10 msec) than the energy confinement time using a center stack ohmic-heating (OH) transformer and/or neutral beam injection. Recently, significant progress has been made in both theory and experiment in Magnetic Reconnection Experiment (MRX) [4,5].

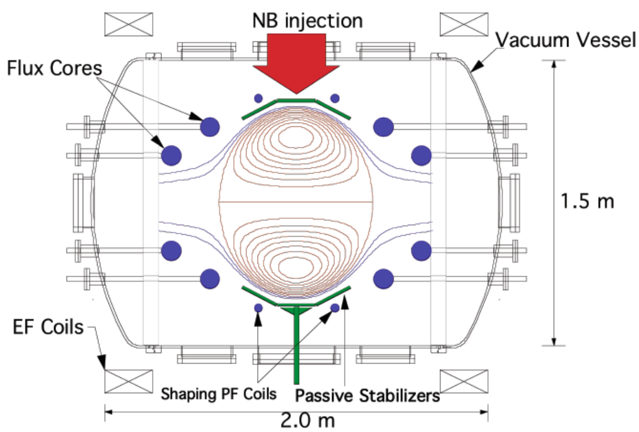

Fig. 1. Schematic of SPIRIT [3]

More recently, it has been shown that the presence of a passive stabilizer is important to form FRCs in a repeatable and relatively stable fashion [6].

One of the essential scientific issues in FRC research is to understand and control the stability of low-n MHD modes. Significant progress in the theoretical understanding of FRC stability properties has been achieved in the past few years. Various effects have been studied theoretically: finite ion Larmor radius effects, the Hall effects, and the effects of sheared ion flow [5]. The global stability properties of oblate (small elongation, E<1) FRCs have been investigated numerically using both 3D MHD and hybrid simulations [5] in direct relation to the SPIRIT concept. It is found that the n=1 tilt mode becomes an external mode when E<1, and that this mode can be effectively stabilized by a close-fitting conducting shell, even in the MHD regime. Interchange mode stability properties are strongly profile dependent, and all $n \geq 1$ interchange modes can be stabilized for a class of pressure profiles with a finite separatrix beta. Although all $n = 1$ modes can be stabilized in the MHD regime, but additional means of stabilizing the $n > 1$ co-interchange (kink) modes are required. This can be achieved by injection of energetic beam ions. Note that by combining conducting shell and beam ions, oblate FRC plasmas can be made completely stable against all MHD modes. Recently utilizing Argon plasmas, the effectiveness of large orbit ions on the stability has been demonstrated [6].

Guided by these extensive theoretical results, a series of experiments studying the dependence of FRC stability on the plasma shape and passive stabilization have been carried out using a conducting center column, a pair of shaping coils, and an extensive set of magnetic probe arrays [6]. It is found that the passive stabilizer is not only crucial for formation of FRC by counter-helicity merging of spheromaks, but also to suppress n=1 tilt and shift modes. The plasma shape is controlled largely by the shaping coils, allowing for the plasma elongation varying from a moderate oblate shape of E=0.6 to an extremely oblate shape of E=0.35. The plasmas stability and lifetime is significantly improved when the elongation is extremely small. The kinetic parameters *S*/E* of these plasmas are relatively large, and thus, the FRC plasmas are more MHD-like. These FRCs contain a significant amount of poloidal flux (5-10mW), which is a step closer to the neutral beam injection (NBI) experiments proposed in MRX.

An important method to sustain FRC plasmas against decay is an injection of energetic beam ions as described in the SPIRIT concept [1-3]. In order to confine such energetic ions in the center region, FRCs with large poloidal flux are required. The maximum flux achieved in MRX is only a factor of 2-3 away from the required value [3, 6]. A complementary way to sustain the FRC flux is to use an ohmic transformer, as demonstrated in TS-3 [7] and recently in MRX [6, 8]. With long-lived, stable FRC plasmas possessing large poloidal flux, the MRX facility provides a unique opportunity to further develop the SPIRIT concept, testing the viability of the FRC concept.

We note that NBI will broaden the scope of the experiment by enabling active control of plasma stability with toroidal rotation and also by providing an additional means of current drive and beam heating. This NBI would induce spinning of the plasma with high velocity of up to $V_{\text{Alfvén}}$, which would in turn help stabilize the global MHD modes. NBI would also decrease the value of s, helping the stability through finite-Lamor-radius effects. In the SPIRIT experiment, NBI of 3-5 megawatts will be employed to extend the lifetime of the plasma beyond ten milliseconds, by maintaining the plasma stability with toroidal rotation [9] and additional beam heating.

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