A Microwave System for Solenoid-free Startup Studies on Pegasus-III[†]

J.A. Goetz[1*], M.W. Bongard[1], S.J. Diem[1], and J.K. Peery[1]

[1]University of Wisconsin – Madison, Madison, WI
[*]jgoetz@wisc.edu

Reducing the need for induction from a central solenoid during startup, ramp-up and sustainment of a tokamak plasma is a critical challenge in magnetic fusion. Solenoid-free startup techniques such as helicity injection (HI) and microwave injection offer the potential to simplify the cost and complexity of fusion energy systems by reducing the requirements of, or need for, a solenoid. This development path is critical to the design of compact, electricity-producing fusion power plants–especially for those based on the spherical tokamak (ST), where a full solenoid is not feasible to implement. Pegasus-III is a new, solenoid-free, extremely low aspect ratio ST ($A > 1.2$, $I_p < 0.3$ MA, $B_T < 0.6$ T, $t \sim 100$ ms) focused on studying innovative non-solenoidal tokamak startup techniques. It will be equipped with a local helicity injection (LHI) system, a coaxial helicity injection (CHI) system, and a 28 GHz gyrotron-based system for electron Bernstein wave and electron cyclotron heating. Pegasus-III will provide key enabling fusion power plant relevant technology to directly test proposed plasma startup and ramp-up scenarios envisioned for larger devices, investigating methods to synergistically improve the target plasma for consequent sustainment.

Microwave injection provides various tools for non-solenoidal startup and sustainment of tokamaks. First, it can provide auxiliary heating during helicity injection to reduce losses from resistive dissipation. Second, microwave heating and current drive techniques are viable "handoff" candidates for non-inductive ramp-up and sustainment following termination of helicity injection. Third, on their own, they may be suitable for non-solenoidal plasma initiation, ramp-up, and sustainment. STs are well-suited for electron Bernstein wave (EBW) heating and current drive because the low B_T and high n_e characteristics of the ST configuration result in a large volume of plasma that is overdense. EBWs can propagate in these plasmas and absorption leads to heating and can also drive plasma current. The absorption mechanism is strong cyclotron interaction near a harmonic resonance. Overdense conditions preclude EC wave accessibility to the absorption layer when launched from the low-field-side of the tokamak. However, during the low-density startup phase, ST plasmas can remain accessible to EC waves and thus heating and current drive scenarios are possible.

The microwave system on Pegasus-III will allow direct tests of synergies between HI and microwave injection methods of plasma startup and ramp-up scenarios. To aid in the development of this 28 GHz system, a synthetic aperture microwave imaging diagnostic [S. J. Freethy, *et al.* 2013 Plasma Phys. Control. Fusion **55** 124010] will be used for the first exploration of EBW emission measurements from HI generated plasmas. This diagnostic will be used to identify operational windows for which EBWs will be effective for heating and current drive by the reciprocity principle. Scenario development will be undertaken to determine if the magnetic turbulence inherent to helicity injection may negatively impact EBW-based heating and current drive schemes by the presence of high-density fluctuations. This may necessitate operation in post-HI plasmas where these fluctuations do not occur and preclude exploring the synergy of microwave heating of HI plasmas. Modeling using the GENRAY and CQL3D suite of codes is being performed to assess the viability of EBW and EC methods under these plasma conditions. This combination of scenario development and modeling will be used to inform system requirements and launcher design.

[†]Work supported by US DOE grant DE-SC0019008