RF Launchers that Survive in the Fusion Reactor Environment

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Summary

RF launchers are a key issue and gap for a burning plasma. Launchers and antennas designed for ITER will not survive in a DEMO reactor. The evolutionary approach is to harden the present day designs with improved materials and cooling. We suggest the possibility of a revolutionary advance for ECH launchers that would eliminate any final mirror near the burning plasma. Research should be conducted to demonstrate advanced launcher concepts. In one concept called "remote steering" that was proposed by C. Moeller of GA, launching occurs from the end of a corrugated waveguide. Steering and control of the microwave beam is done by preparing a suitable mixture of guide modes upstream. The reliability and maintainability of such an antenna would be very attractive for DEMO.

Issues, Gaps

The issue and "gap" are clearly stated in the Report: Priorities, Gaps and Opportunities: Towards A Long-Range Strategic Plan For Magnetic Fusion Energy (Greenwald Panel Report, 2007). The report states within Theme B (Taming the Plasma Material Interface) that RF Antennas, Launching Structures and Other Internal Components are a major concern. Finding 10 of the Report explicitly states the concern to "Establish the necessary understanding of plasma interactions, neutron loading and materials to allow design of RF antennas and launchers, control coils, final optics and any other diagnostic equipment that can survive and function within the plasma vessel." Gap 7 states the need for "Integrated understanding of RF launching structures and wave coupling for scenarios suitable for Demo and compatible with the nuclear and plasma environment. The stresses on launching structures for ICRH or LHCD in a high radiation, high heat-flux environment will require designs that are less than optimal from the point of view of wave physics and that may require development of new RF techniques, new materials and new cooling strategies."

The issue is easily understood and simply stated. RF antennas are complex structures that are part of the first wall. Present day designs of RF antennas would not be able to survive under the heat loads expected in a fusion reactor or a DEMO device. For heating at lower frequencies (ICRF, LHH), the antenna must be designed to provide good coupling to the plasma while surviving under the high heat load conditions. For ECH, a major issue is the final mirror, which must have very high reflectivity that is unaffected by long exposure to the burning plasma.

Development Opportunities and New Ideas

RF heating for ITER consists of ICRF and ECH/ECCD, although the heating system may be increased in power and augmented with LHH in the future. RF heating of the ARIES AT and RS plasmas, which serve as prototypes for a DEMO, includes ICRF and LHH. But, the ARIES designs were conducted years ago, before the development of megawatt gyrotron technology and the commitment of ITER to a major ECH system. Based on successful ITER operation, we assume that ECH/ECCD will be (or should be) used on DEMO.

The evolutionary development path for improved RF launchers involves strengthening and hardening existing RF launcher concepts. These advances would rely on the development of materials and cooling concepts that are suitable for the first wall, then using these approaches to design rugged antennas that could survive at the plasma periphery. This is an important approach and should be pursued. It is most likely the necessary approach for ICRF and LHH antennas.

Launchers for high frequency microwaves, used in ECH, ECCD and EBW heating, have different requirements and different opportunities. The difference arises because high frequency microwaves can be controlled by waveguides, as in low frequency microwave applications, or by mirrors, as in an optical beam, or by a combination of these two approaches.

In present day ECH launchers, a final mirror is used to direct the microwave power toroidally and poloidally to achieve optimal coupling to the plasma. The final mirror must have a highly reflecting surface to reduce the heat load on the mirror itself. In practice, the high reflectivity may restrict the mirror surface material to copper or a copper alloy. The reflection occurs in about one skin depth of the surface, where the skin depth is 0.15 microns thick at a frequency of 200 GHz. The obvious concern is that this surface will not last for many years when exposed to the burning plasma.

The opportunity exists to devise new antenna concepts that effectively move the control of the launcher away from the burning plasma interface to a remote location, such as behind a shield wall. Such “remote steering” is a real possibility for high frequency microwaves. It depends on preparing a mixture of waveguide modes that will propagate to the end of a waveguide with just the right phase to launch in the desired toroidal or poloidal angle. The first proposal and results on this concept were obtained by Charles Moeller and colleagues at General Atomics and additional research has been recently conducted in Europe and Russia. However, remote steering will not be used on ITER and is not scheduled for test on any major device at this time.

If the remote steering concept is successful, there will be no final mirror and no “launcher” for the ECH /ECCD system. Instead, there will be an opening with a corrugated waveguide. The ohmic loss on this waveguide is very low so that it can be made of any metal, including a high resistivity metal, such as tungsten or molybdenum. This would represent a complete solution to the RF launcher problem.

For lower hybrid heating of DEMO at a frequency near 5 GHz, remote steering may also be feasible. The large ports of DEMO would allow highly overmoded waveguides, with dimension more than ten wavelengths in diameter. This could be further investigated.

Research Thrust

<u>Design</u>
The proposed concept should be considered in general terms. The question that is being asked is how to simplify the final few meters of the launcher structure by eliminating the mirror from the

ECH system. The concept that was mentioned, remote steering, is a specific concept. There may be other concepts such as optical approaches. The specific concept of remote steering should be further investigated through design activities and theory. A major challenge is in microwave engineering. Remote steering requires preparing a specific mixture of modes and successfully transmitting it to the plasma. This waveguide approach to remote steering may also be supplemented by consideration of a true optical approach using mirror relay lines and a final waveguide run. This area of research would be open to a wide range of innovative concepts. These concepts could be tested by theoretical research and modeling. Designs could also be tested at low power in cold test laboratories.

Test Stand Demonstration

The proposed concept should be tried on an ECH test stand prior to implementation on a major plasma heating experiment. An ECH test stand at a national laboratory or at a major fusion laboratory should be employed for such a test.

Confinement Experiment Demonstration

The remote steering concept should also be investigated in a high power ECH experiment. The DIII-D ECH system would be ideal for such a test.