Multi-physics of RF, Antennas, the SOL, and the Walls

Author: David Smithe, Tech-X Corporation

The main area of multi-physics application for RF involves the disparate time-scales of equilibrium evolution (10^{-5} to 10^{-3} seconds) and the RF frequencies (10^{-10} to 10^{-8} seconds). The equilibrium provides a background (essentially zero-frequency) plasma for RF modeling, and RF modeling provides quasi-linear (essentially zero-frequency) thermal, momentum, and current drive terms to the core equilibrium evolution equations. The time-scale factor of 10^5 implies that this is indeed an obvious and trivial separation of time-scales coupling.

The core is not the only region affected by RF, though. Even when most of the RF power is successfully applied to the core, one usually notices a core density increase when the antennas are powered, which is likely a result of thermal loading to antenna and wall and outgassing. And if the RF power is not successfully applied to the core, then it may be absorbed in or next to the SOL, then quickly transporting to the diverter, as is sometimes seen in NSTX [1], in which case the interaction with SOL and diverter become visibly obvious. And of course, an increase of impurities in the plasma is now understood to be due to sputtering as plasma ions accelerate in the RF rectified sheaths before colliding with the wall.

Thus, in terms of fusion device "actuators", this means that RF is not a simple "actuator", simply heating, or simply driving current, but rather a complex one, providing several different modifications to the operating state simultaneously. When trying to model or simulate the RF, when taking into account the complexity of these behaviors, we include and refer to its various different "multi-physics".

In the RF SciDAC (CSWPI) we have begun a process of assembling a simultaneous and consistent treatment of these multi-physics effects, in particular the inclusion of RF sheath potentials in the same calculations as the antenna near field loading calculation [2,3], so that we may understand in a quantitative manner the simultaneous RF power introduction and impurity production actuations. Very recent work has also revealed a pressing need to understand possible outside-SOL edge density modifications that may accompany powering of the antenna, and the transport of RF power through that low density region [4,5]. Indeed, if ponderomotive or other effects push that outside-SOL density below the ion plasma frequency, a resonance can appear that would result in local edge power absorption. Thus, we have just begun the inclusion of another area of multi-physics in the edge.

This area in particular, opens up, indeed may require, interaction between RF scientists and plasma equilibrium scientists, as this is a new, and yet another, area of RF quasi-linear drive affecting the slower time-scale background equilibrium. Coincident with this new interest in the RF community is an nascent effort in the plasma equilibrium field to extend their modeling domain to include the full thickness of the SOL region, separatrix, and outside of that [6]. Of course, the interest in the equilibrium community is to more quantitatively model the plasma that is interacting with the diverter plates. However, both RF and equilibrium communities must understand the strong actuator effects that a powered RF antenna can have on this region. Thus, this white paper is, at a minimum, proposing a new direction of collaboration between these two communities, insuring that RF actuations are included in SOL modeling, and in return, insuring that RF power modification to the SOL, and outside SOL-regions are included back in the RF calculations.

That said, there are yet more areas of new collaboration and multi-physics inclusion needed relating to the use of RF power. Edge modeling researchers have worked to build up advanced and accurate models of sputtering from materials, but are in need of good estimates of incident fast ions. RF antenna calculations including sheath potentials should be able to provide good estimates of ion flux, and energy distribution, but need to incorporate better sputtering models if they are to accurate predict the impurity production actuation.

Finally, tying in the multi-physics of antenna, wall, and diverter thermal loading, outgassing, and neutral evolution and recycling is an area where much remains to be done, and where in a five year period, one might envision the beginnings of a collaborative effort to improve the consistency between RF modeling and this area.

References

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