Benefits of Radial Build Minimization and Requirements Imposed on ARIES Compact Stellarator Design

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After two decades of stellarator power plant studies, it was evident that a new design that reflects the advancements in physics and improvements in technology was needed. To realize this vision, the multi-institutional ARIES team has recently launched a study to provide perspective on the benefits of optimizing the physics and engineering characteristics of the so-called compact stellarator (CS) power plants. The primary goal of the study is to develop a more compact machine that retains the cost savings associated with the low recirculating power of stellarators, and benefits from the higher beta, smaller size, and higher power density, and hence lower cost of electricity, than was possible in earlier studies.

It is widely recognized among stellarator researchers that the minimum distance between the plasma boundary and the middle of the coil (Δ_{min}) is of great importance for stellarators as it impacts the machine parameters. Specifically, it controls the minimum major radius and the maximum field at the coil. Techniques for minimizing the radial build have made impressive progress during the first year of the ARIES-CS study. During this period, several blanket/shield systems have been examined: one solid breeder-based system (Li_4SiO_4/FS/Be/He) and four liquid breeder-based systems (Flibe/FS/Be, LiPb/SiC, LiPb/FS/He, and Li/FS/He). As predicted, each concept offers advantages and drawbacks and an integrated study with guidance from the economic analysis and maintenance scheme will later identify the preferred blanket/shield concept for ARIES-CS.

The limited space assigned for the internals (blanket, shield, and vacuum vessel) calls for a well optimized, highly compact radial build at Δ_{min} in particular. Our analysis indicates that the radial distance between the plasma and coil center varies widely with the proposed blanket concepts, ranging from 1.3 to 2 m. A novel approach has been developed for ARIES-CS where the blanket at the critical area surrounding Δ_{min} has been replaced by a highly efficient WC-based shield. As a result, an appreciable 20-30 cm savings in the radial build has been achieved, reducing the major radius by 15-20%, which is significant. This approach places a premium on the blanket that covers ~90% of the first wall area to supply all the tritium needed for plasma operation. The economic benefit of this approach is yet to be determined and the added engineering problems and complexity will be addressed during the remaining period of the study. Future work present some challenges: how to integrate the thinner WC-shield with the blanket system, determining if there is a need for a separate decay heat removal loop for the WC-shield, and how to handle the relatively massive WC modules. This paper covers the details of the radial build optimization process that contributed to the compactness of ARIES-CS and describes how the ARIES team has tackled the emerging design problems. Compared with previous designs, the major radius of ARIES-CS has more than halved, dropping from 24 m to less than 10 m, making a step forward toward the feasibility of a compact stellarator.