National Compact Stellarator Experiment (NCSX) Vacuum Vessel Manufacture

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The National Compact Stellarator Experiment (NCSX) is the first of a new class of stellarators known as “compact stellarators.” Stellarators are a class of magnetic fusion confinement devices characterized by three-dimensional magnetic fields and plasma shapes and are the best-developed class of magnetic fusion devices after the tokamak. The stellarator concept has greatly advanced since its invention by Dr. Lyman Spitzer, the founding director of the Princeton Plasma Physics Laboratory (PPPL), during the 1950’s. A traditional stellarator uses only external magnetic fields to shape and confine the plasma. The differentiating feature of a compact stellarator is the use of plasma current in combination with external fields to accomplish plasma shaping and confinement. This combination permits a more compact stellarator design.

NCSX requires a highly shaped, three-period vacuum vessel, which means the geometry repeats every 120º. Stellarator symmetry also causes the geometry to be mirrored every 60º so that the top and bottom sections of the first (0º to 60º) segment can be flipped over and serve as the corresponding sections of the adjacent (60º to 120º) segment. The vessel will be constructed in full field periods and joined together at welded joints. Numerous ports are provided for heating, diagnostics, and maintenance access. Several port sizes and shapes are used to best utilize the limited access between modular coils.

Each 120º segment is called the Vacuum Vessel Sub-Assembly (VVSA) and includes associated port extensions and spacer assemblies, which are critical components for NCSX. The VVSA’s, fabricated of N06625 Inconel material, are toroidal (donut-shaped) in major diameter, but highly shaped in the poloidal (short) direction. Three (3) 120º VVSA’s comprise the complete NCSX vacuum vessel. Each VVSA includes a field period assembly (the basic vacuum vessel shell), associated port extensions (including blank off flanges, seals, and fasteners) and one connecting spacer assembly.

Fabrication is a significant challenge, since the vessel has a contour closely conforming to the plasma on the inboard side. Inconel 625 was selected over stainless steel primarily because of its low permeability (both in the parent and weld material) and high electrical resistivity. The vessel shell is formed by pressing plate sections, then welding them together to form the finished shape. Segmentation of the vessel is driven by assembly requirements and inherent fabrication limitations. Fabrication by pressing requires the panel sections to be removable from the tooling dies. This requirement must mesh with the desire for half-period segments. The result is that the number and geometry of poloidal segments is dictated by the die contour.

The form tolerance of the vessel must be very accurate in the inboard region, with a tolerance of +/- 0.188 inches to provide adequate clearance to both the coils and the plasma. These tolerances must be held after the vessel is completely welded and assembled, so intermediate heat treatments during fabrication may be necessary.