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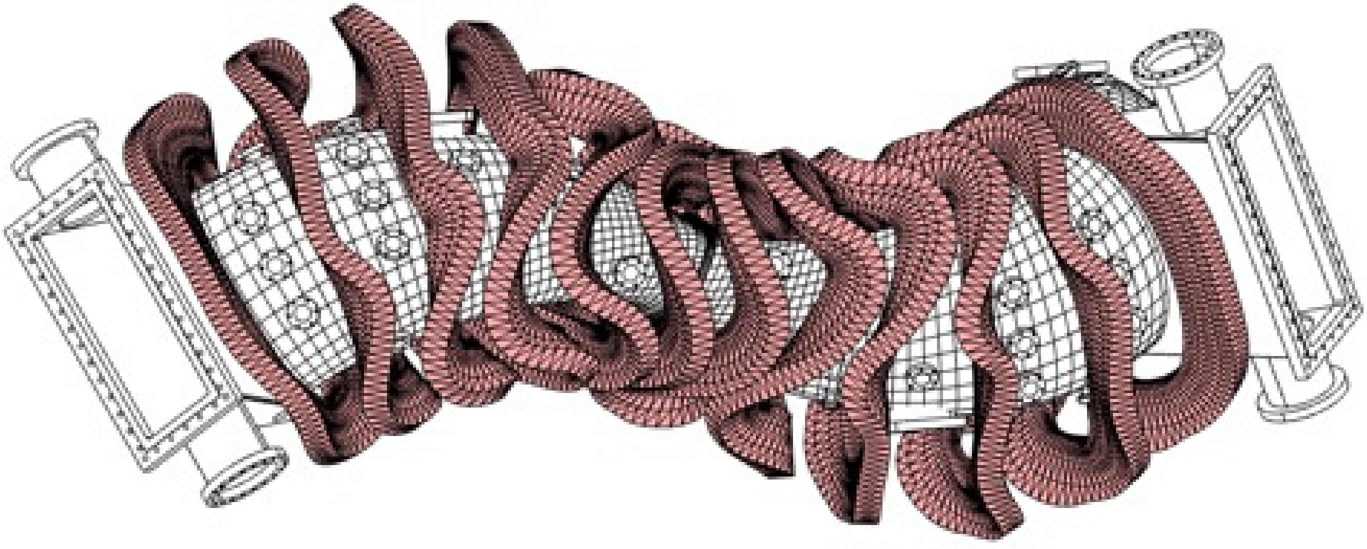
In this issue . . .

HSX returns as a lean, clean, plasma machine

Although plasma-wall interactions are not the star of the show in fusion energy research, if you don't treat them carefully the show will not go on. Plasma operations in the Helically Symmetric Stellarator (HSX) stellarator are no exception. In this modestly sized device, the stainless-steel vessel serves double duty since it not only provides ultrahigh-vacuum conditions, but is also the surface with which the plasma intersects. The absence of dedicated plasma-facing structures maximizes the space available for confined plasma but limits the options available for controlling plasma-wall interactions.

When HSX was operated with a 0.5 T confinement field starting in 2001, modest plasma performance was achieved with no detrimental effects from plasma-wall interactions. As the device moved to higher field strength (1 T) and higher input powers in 2006, plasma performance was spoiled by sputtering of the steel wall, and wall conditioning became a necessity. Injecting methane during unconfined glow discharges in the vessel was initially used to coat the plasma-facing walls with carbon. This prevented steel sputtering and allowed hotter plasma conditions to be achieved. With carbonized walls, operations were limited by the fact that carbon tends to retain hydrogen as plasma conditions cool between discharges. This hydrogen is then released during subsequent discharges. This meant frequent



helium glow discharge cleaning was needed to maintain control of the plasma density.

To improve density control, boronization was used to condition the walls. This was a great success. Boronization displayed much lower hydrogen retention rates than carbon, while preventing sputtering of the steel wall—and that was a good thing. Boronizing on a regular basis allowed high-performance plasmas to be studied in HSX and plasma wall interactions seemed to be solved, but eventually it became clear that HSX had gotten too much of a good thing. Plasma densities behaved unpredictably, and it became clear that wall conditioning was not going to solve this. Plasma operations were paused, and a visual inspection of the inside of the vessel revealed macroscopic deposits of dust at the bottom of the device and adhered to the wall, as can be seen in Fig. 1(a).

Although high-tech cleaning solutions were considered, ultimately one of the HSX group's key assets was leveraged to clean the device: highly motivated graduate students. Vacuum cleaners, rotating steel brushes, and determination were used to remove the dust from the inner surfaces of this highly shaped device. HSX's modest size (average plasma minor radius = 0.12 m) prevents personnel from entering the device. This limited direct exposure to any dust liberated by the cleaning process. Additional safety precautions, including wearing personal protective equipment (respirators, goggles, gloves and hooded coveralls), were used to further limit any exposure. As can be seen in Fig. 1(b), despite limited access, this cleaning procedure resulted in significantly cleaner surfaces. To further clean and smooth the wall argon glow discharge cleaning, shown in Fig. 1(c) was performed. During initial argon glow discharge cleaning, arcing was observed along the walls of the vessel likely because of the remaining roughness from the steel brush cleaning. After several hours of argon glowing this arcing disappeared, showing the effectiveness of this technique in smoothing plasma-facing walls.

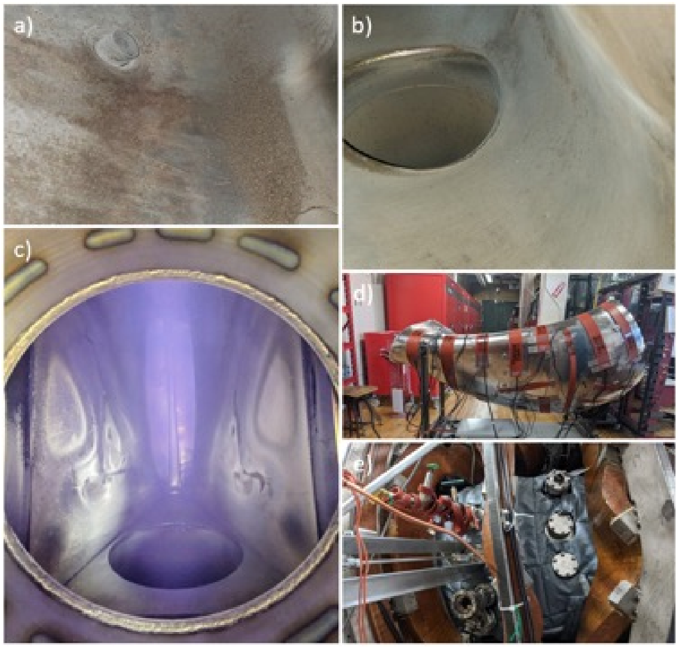


Fig. 1. The inside of the vacuum vessel is seen in (a) before vessel cleaning with significant dust accumulation and (b) after cleaning. (c) Shows an argon glow cleaning discharge in the plasma vessel. (d) A test section of the vacuum vessel with heating tape for the baking system is shown. (e) The grey blanket of the newly installed baking system is shown on HSX.

In parallel with the wall cleaning HSX was upgraded with a baking system. Figure 1(d) shows the heating tape for the baking system installed on a test section of vacuum vessel. Figure 1(d) shows a current picture of HSX where the grey insulating blanket can be seen. The benefits of this baking system were demonstrated by the fact that ultrahigh-vacuum conditions with pressures down to 5×10^{-8} torr were achieved within a few weeks. Previously this type of vacuum conditions would have required a pump-down of several months.

And now the show goes on at HSX. The success of the manual cleaning of the HSX wall has now been demonstrated by recent discharges in HSX that displayed reproducible density evolution and strong stored energy, are shown in Fig. 2. These discharges were conducted with a 0.5 T confinement field and 50 kW electron cyclotron resonance heating (ECRH) because plasma operations on the unconditioned steel wall have been well established in these conditions. Near-term operations will leverage these low-impurity operating conditions to better understand how changes in impurity sourcing and recycling of hydrogen from the walls affect other plasma parameters.

HSX will soon be transitioning back to its previously established 1 T high-confinement, higher-input-power operating parameters and subsequently pushing beyond them. A higher frequency ECRH system is currently being installed. This system will allow access to higher density regimes. Higher plasma densities will reduce neutral penetration and support experiments to understand intrinsic plasma flows and turbulence in quasi-helical stellarators. These higher performance conditions will likely require a return to wall conditioning. The process of cleaning the plasma-facing wall has given us a better understanding of the benefits wall conditioning has provided to plasma operations and the assurance that these conditions can be reset when they become detrimental to plasma operations.

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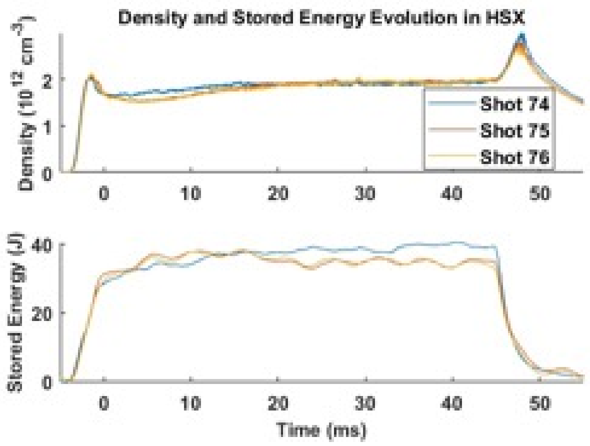

Fig. 2. The time evolution of the (a) line-averaged density and (b) stored energy for a series of typical discharges in the newly cleaned vessel.