# A Vacuum Bakeout System for the HSX Stellarator Upgrade


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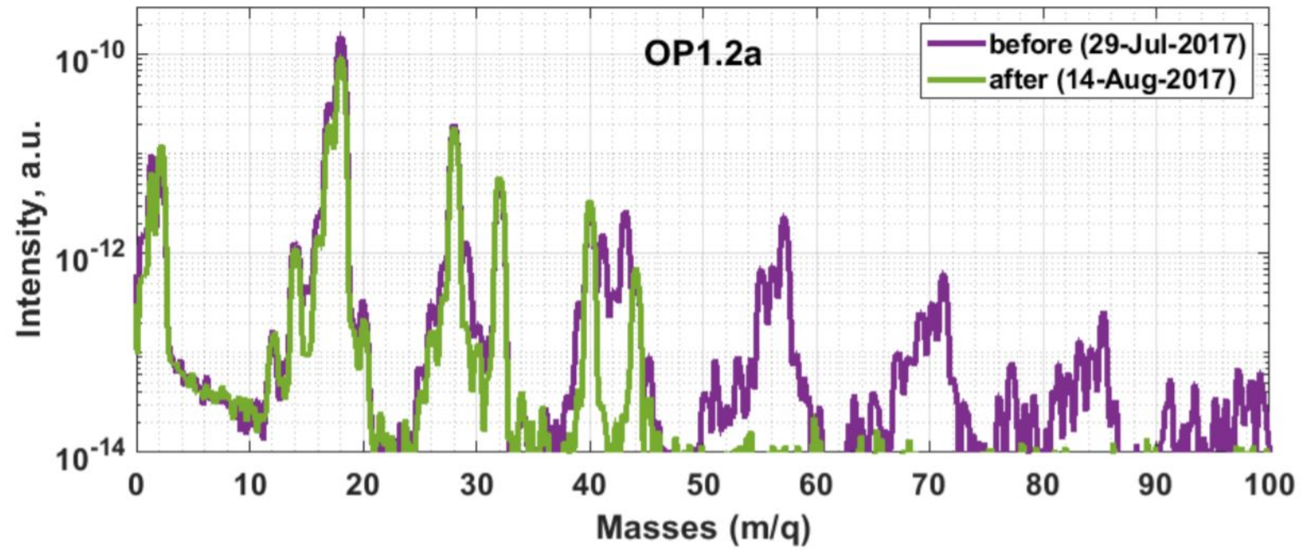
## Overview

- Reducing neutral influx from the vessel wall is of critical importance for the higher power and density discharges of the HSX upgrade.
- A baking system has been designed to heat the HSX vacuum vessel to 150C to aid in desorption of hydrogen, water vapor, and other impurities.
- Considerations have been made to ensure uniform heating and to protect vacuum vessel components.

## Motivation for Baking

- Desorption rate of adsorbed gases from metals is heavily temperature dependent [1].
- Baking has been shown to significantly improve performance in DIII-D [2].
- W7-X uses 150C baking in their wall conditioning regimes [3].
- Baking the HSX vessel is expected to remove impurities and yield better wall conditioning when combined with glow discharge cleaning and boronization.




Impurity levels before and after initial W7-X baking of 150C [4]. Significant reduction of heavy impurities, as well as ~2x reduction of 16 ($CH_4$), 18 ($H_2O$), 28 (CO, $C_2H_4$, $N_2$).

## Design Constraints

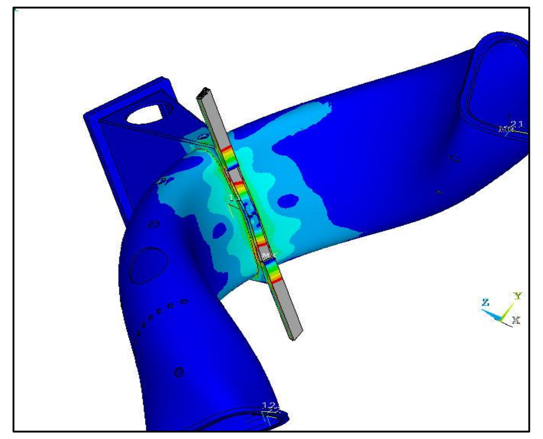
**Maximum Temperature:**
- Maximum temperature is currently limited by Indium wire seals on boxport covers, which degrade at 100C.
- After seals are upgraded to Helicoflex, maximum temperature will be 150C.

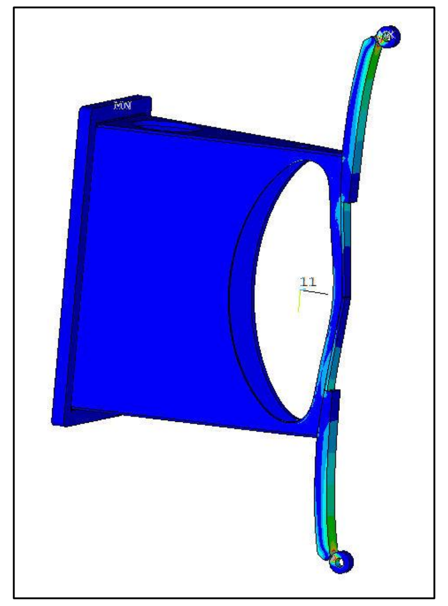
**Uniform heating:**
- Minimizing temperature gradient is important for good quality bake [4].
- Reducing temperature difference across weld joints of vessel is necessary to prevent damage from repeated heating and cooling cycles.

**Vessel clearance:**
- Minimum spacing between vessel and field coils is 1cm. This limits the amount of insulation that can be used.

## Ansys Stress Simulation

- Verify that vessel can survive thermal expansion from uniform heating of 150C.

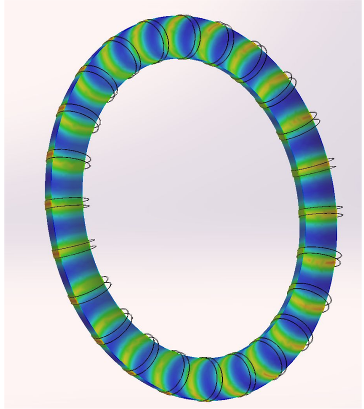




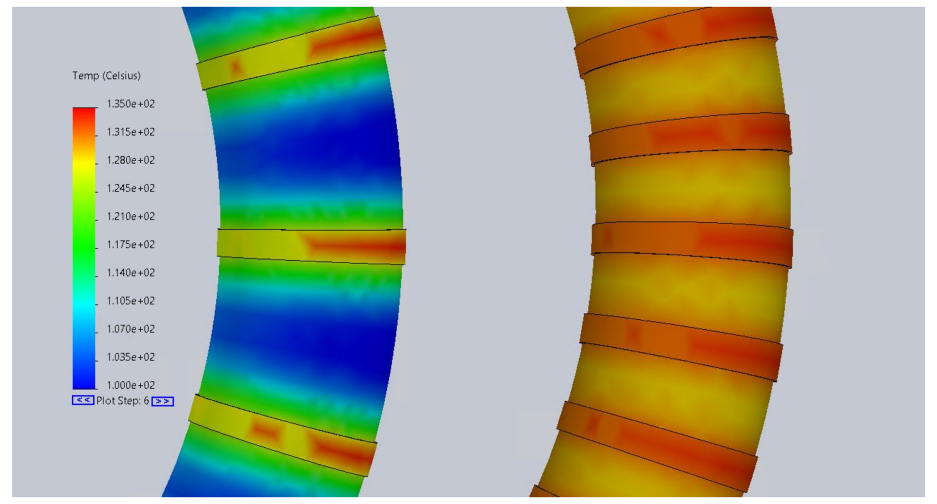
- The yield strength of AISI 304 stainless steel is 215 MPa
- Simulation found that stresses in the vessel were fairly low (<30 MPa)
- Large amount of stresses on solid bar in back of boxport, where vessel is mounted to superstructure (500 MPa)
- However, this stress is mainly from vertical expansion, and the simulation assumed the boxport bar was also heated. If bar is not heated, then this stress is expected to be minimal. We will still monitor this area closely during baking.

## SolidWorks Thermal Simulation

- A model with simplified geometry was used to determine heater power and insulation requirements to achieve 150C.

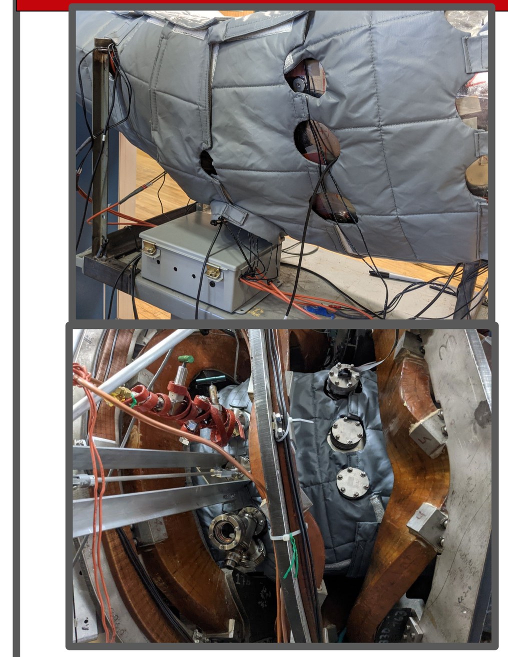


- Model includes material properties for vessel and heaters, as well as both radiation and convection heat losses.
- With 1cm of fiberglass insulation, 5kW of heating power is sufficient to maintain baking temperature.
- It was found that even with insulation, significant temperature gradients occurred due to the low thermal conductivity of stainless steel.



- Heating strips must be placed close together for uniform temperature.
- Doubling the amount of heaters while maintaining total power reduced average temperature gradient from 1.4 K/cm to 0.3 K/cm.

## Insulation

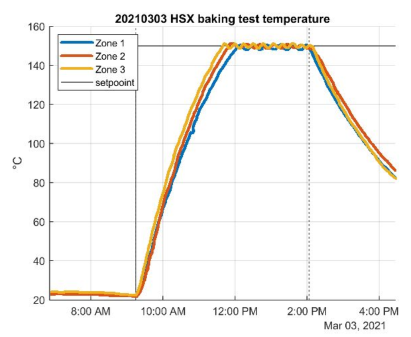


- Insulation is teflon covered fiberglass, rated for 300C continuous exposure.
- Due to the HSX vacuum vessel's unique shape, specialized manufacturing of insulation was necessary.
- Insulation is split into poloidal strips to aid in installation around field coils.

## PID Control System

- Each half period of vessel is divided into 3 individually controlled zones to ensure uniform heating.

Test stand constructed to develop PID control system



- Thermistors mounted on heaters and vessel monitor temperatures at key points
- Heater duty cycles are modulated to gradually heat vessel while keeping zones at similar temperatures

## Project Status

**Completed:**
- Baking system is fully designed and ready for installation

**In Progress:**
- Replace Indium seals with Helicoflex
- Mount strain gauges on HSX vessel to measure expansion during baking

**Future Work:**
- Monitor time traces of impurities and total pressure for the entire duration of baking
- Evaluate plasma performance differences after vessel wall is properly conditioned

## References


[1] Tom Wauters et al. 2018 Nuclear Materials and Energy 17 235-241
[2] K.L Holtrop et al. 1996 GA-A22474
[3] H.S. Bosch et al. 2017 Nucl. Fusion 57 116015
[4] A. Goriaev et al. 2020 Physica Scripta T171



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