Expansion vessel for supercritical hydrogen in a spallation neutron source moderator circuit

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Motivation

Parahydrogen around 20 K and above critical pressure is a preferred moderating fluid for conditioning of cold neutrons. Heat loads demand recooling and circulation in a closed loop. The engineering challenge is to keep the pressure and temperature within tolerable levels for expected or sudden changes of the neutron heat load.

Pressure control possibilities

Hydrogen acts almost as an incompressible at temperatures around 20 K. Small variations in the mean temperature for a constant specific volume result in large pressure fluctuation in a rather short time. There are three opportunities.

- Adjusting loop volume (ca. 1.2 %).
- Keep mean temperature constant (el. heater in LH\textsubscript{2} and/or energy balance over HX).
- Adjusting loop mass (ca. 1.2 %) by installing a small vertical vessel in a side arm.

Passive expansion vessel

The vapor space at the top of the buffer acts as a gas spring dampening the pressure increase due rising mean loop temperature and inflow of 17.25 K liquid into the vessel.

![Figure 1. Simplified flow scheme of a moderator cooling circuit based on supercritical parahydrogen of a high-power spallation neutron source at 100 % beam power.](Image 77x2193 to 593x2337)

![Figure 2. Phase diagram of parahydrogen.](Image 111x217 to 372x500)

![Figure 3. Helium gas-backed accumulator for volume variation (left), passive (middle) and actively controlled expansion vessel (right).](Image 412x217 to 659x500)

![Figure 4. Passive expansion vessel exemplary for a total volume of 60 L with transition from beam OFF (left) to beam ON (right) and accompanied isentropic compression.](Image 1423x1377 to 2164x1660)

![Figure 5. Active expansion vessel: transition from beam OFF (left) to beam ON (middle) and open control valve for vapour release and cool-down to pump suction side; transition from beam ON (middle) to beam OFF (right) and necessary heating to re-establish vapour fraction.](Image 2751x35 to 3652x531)

Table 1. Partial derivatives for mean temperature change and pressure increase over loop.

<table>
<thead>
<tr>
<th>State</th>
<th>( \frac{\partial T}{\partial p} )</th>
<th>( \frac{\partial p}{\partial T} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON</td>
<td>0.003801</td>
<td>0.000380</td>
</tr>
<tr>
<td>OFF</td>
<td>0.003801</td>
<td>0.000380</td>
</tr>
</tbody>
</table>

Isentropic compression for 17.25 to 18.75 K, 300 L inventory and a buffer volume of 60 L (85 % vapor) results e.g. in a pressure rise of 0.25 MPa.

Numerical approach

The ideal process of isentropic compression of the 40 K vapor space does not take into account the compressible feature of the transition zone, heat conduction or mixing effects. Therefore a CFD simulation was set up. High resolution table based hydrogen property data allow numerical calculations in the range between 13 to 2 MPa and 16 to 100 K. Compared to the isentropic compression the pressure increase in the CFD simulation is smaller because of taking into account the compressible transition zone and forced mixing due to the incoming flow of cold hydrogen.

![Figure 6. Geometry, initial horizontal temperature profile and respective specific volume at inflow line for CFD calculations.](Image 3120x659 to 3689x1154)

![Figure 7. CFD simulation of inflow followed by outflow for the 60 L passive expansion vessel with transient pressure and temperature distribution.](Image 3516x2036 to 3683x2432)