Design of re-condensing cryostats for long term use in magnet beamline applications

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Why not Cryofree™?

Cryofree™ - no liquid helium
- Eliminates cost of liquid helium
- Liquid storage and handling
- No Helium in the event of quench
- No helium vessel – maximises experimental space, reduces opportunities for leaks and reduces costs

Design constraints
- Coil design temperature
- Wire hysteresis/ramp losses
- Cool down times (without acceleration)
- Outgassing, generally not UHV compatible
Why not Cryofree™?

Cryofree™ - Performance example, ~250Kg cold mass

- 8 day cool down
- Energy dissipation from hysteresis losses
- Coil temperatures with magnet ramp
Why recondensing?

Recondensing – helium + refrigerator (PTR)

- Nitrogen pre-cool allows faster system set up
- Liquid helium, so stable, essentially isothermal environment
- Positive pressure maintained via PID control
  - protect against air ingress
- Helium provides system “ride through”, against power outages etc.
  - maintains experimental environment/preventing system warm up
- Excess condensation capacity
  - allows condensing of helium flows for example through variable temperature inserts, dilution refrigerators etc.
- Allows trade off between cryogen consumption and speed of operation ie faster magnet sweeps and rapid sample cool down (often significant criteria where beam time is expensive and set up times need to be minimised)

Current leads
Thermally linking the current lead to the PTR 1\textsuperscript{st} stage allows:
• Fixed upper temperature in an HTc applicable range
• Leading to low or zero losses during magnet sweeping

Losses dependent on:
• Sweep rate
• Ullage volume (time to exceed system exhaust valve pressure)
• Insert operation
• Prior operation (recovery from other perturbations such as high sample temperature operation)
Design features – current leads

**HTc Current lead - experimental data**

- **Field, PTR 1st stage T**
- **Field, PTR 1st stage temperature during field sweep**
- **Field, Vessel pressure during field sweep**
- **Field, Helium level during field sweep**
- **Field, Vessel pressure**
- **Field, Helium level**
- **Magnetic field**
- **PT1**
- **Magnetic field**
- **Pressure**
Some applications require the experimental space to be continuous with a beam line vacuum

- UHV compatible construction materials, cleaning and seals
- No multi layer insulation
  - High radiation heat load driving twin cold head requirement
- Support members from stainless steel
- UHV cleanliness
  - Maintained through all stages of manufacture, from receipt of UHV clean components through final assembly
- System bakeout temperatures limited by cold head and magnet components

System safety
- It is mandatory that cryogenic vessels have a relief device on their vacuum chamber to prevent over pressurisation. Overcome with a fully welded burst disc design.
Design features – radiation shield

Neutron and X-ray facilities require specific access to the environmental space giving complex constraints on the system design
- Magnet aperture profile tends to absorb thermal radiation
- Radiation shield apertures to minimise material that may scatter neutrons etc
- Foil “windows” to cover shield apertures
- Polyimide windows for X rays

Eddy currents – system resilience against quench
- Slotted shields but mechanically weakened structures
- Increase resistivity (via aluminium grade) but decreased thermal conductivity and increased thermal gradients
Design features – high temperature sample environments

High temperature experiments
• 800K sample environment available
• Sample in vacuum
• Takes system out of fully recondensing regime as:
  o VTI flow required to maintain indium joints below 400K
    this exceeds recondensing capability
  o Heat load from VTI temperature causes inner radiation
    shield temperature increase and consequent 4K heat load

![Graph showing temperature vs time for 800K sample rod at 800K]
Customer requirement for persistent 8T horizontal bore system with **zero cold head** vibration:
- 10 hour experimental time
- Zero helium loss
- Maximum 14 hour “recovery” time

Achieved by
- Sub atmospheric, 500mbarA to 1300 mbarA
- Helium volume, sufficient enthalpy for ride through
- Radiation shield mass, sized to limit warm up and 4K radiation load

Safety
- Helium buffer volume around service ports to prevent air ingress when sub-atmospheric
Summary – Re condensing beamline systems

Enabling cost effective, low (and high!) temperature, high access, high magnetic field beam line environments