Fusion Reactor Technology I
(459.760, 3 Credits)

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Contents

Contents

Vacuum Vessel

- Sources of stresses (in decreasing order of importance)

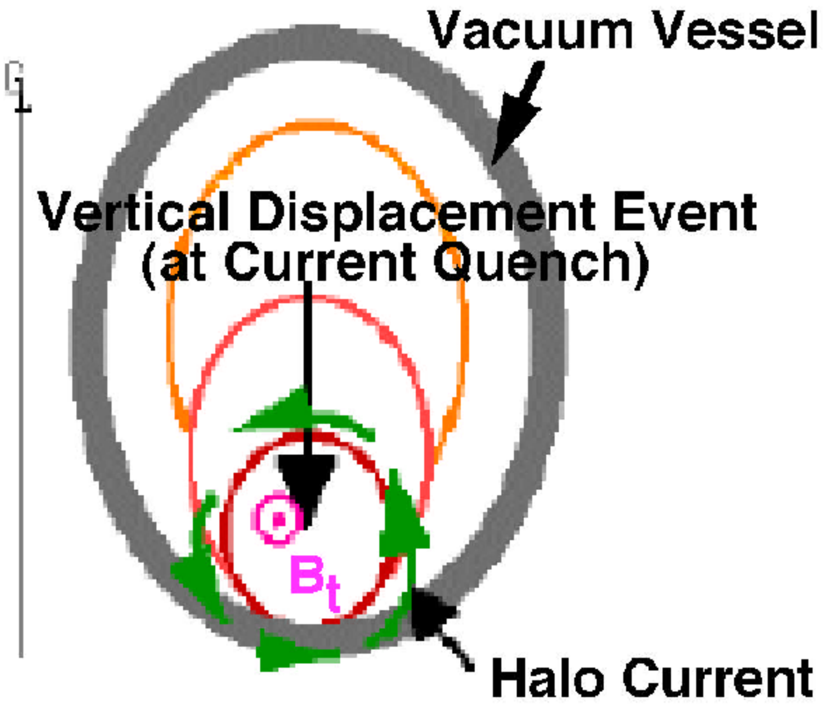
- Disruption-induced currents
- Thermal gradients
- Air pressure
- Human malpractice
- Diagnostic loads
- Currents induced during plasma start-up
- Diagnostic flange bolting

Vacuum Vessel

- Disruption-induced currents

- Arising when the plasma terminates rapidly
- Commutating plasma current into the vessel
- Reacting with the externally imposed poloidal fields, giving rise to inward pressures on the vessel: ~ 1 bar (several hundred kPa)
- The commutated current getting around port-holes causing regions of high current density
  → crossing of the toroidal field
  → producing very large local stresses
- VDE (Vertical Displacement Event): scraping off up to ~20% of the toroidal plasma current where it flows helically (halo current)
  → resulting in large currents crossing the toroidal field within components mounted inside the vessel
  → severely stressing the mountings

Vacuum Vessel



How to achieve a high strength vessel?

Vacuum Vessel

- Toroidally continuous thick metal vessel

- Low loop resistance
  → large currents induced during plasma start-up
  → creating a vertical field which inhibits the gas break-down unless compensated

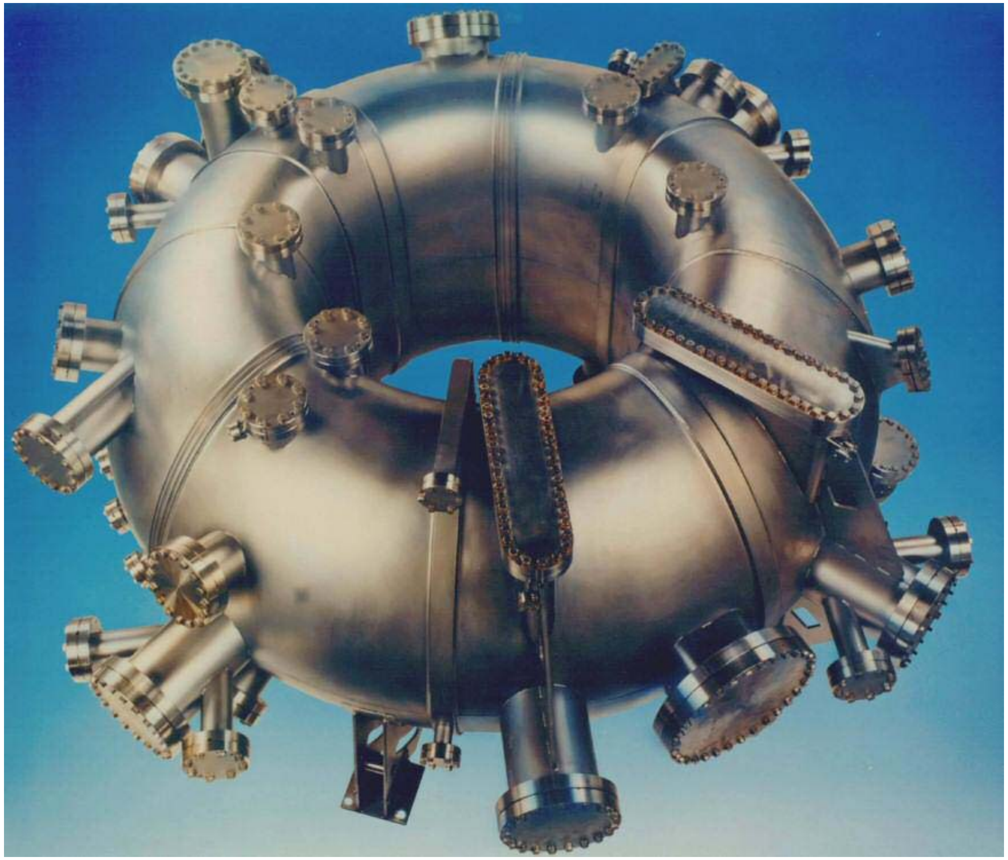
- Gapping the vessel

- Requiring robust insulating joint of high vacuum specification
- Need to consider the plasma disruption effects on coils and structural components

- Putting the vacuum vessel outside the PFCs

- Having difficulties with maintaining the vacuum standard, given the large number of components and the range of materials selected for items mounted inside the vessel

Vacuum Vessel



COMPASS-D vacuum vessel:

Continuous welded inconel (frequently adopted in smooth vessel designs due to its high resistivity and mechanical strength and reliable low permeability)

3 mm thick

Vessel Conditioning

- Why high vacuum standard needed in a tokamak?

- To keep the radiated power and loop voltage low
- Operation difficult with base pressures above about $2x10^{-7}$ torr of H_2O+CO
- Better than about $5x10^{-8}$ torr, the plasma behaviour depending on the conditions of the walls, limiters and divertors particularly for plasmas with hydrogen isotopes due to plasma chemistry causing H_2O, OH, CH_4, etc to be produced and then dissociated in the bulk plasma

Vessel Conditioning

- Routes to a high vacuum standard

- The achievement of an all-metal set of vacuum seals, welded wherever reasonable
- The avoidance of materials with high vapour pressures (e.g. brass, plastics, etc.)
- The avoidance of trapped volumes (e.g. in screw threads and between mating surfaces)
- The banning of marker pens and crack-detecting dye penetrants for use inside the vessel
- The avoidance of the use of cleaning fluids with tightly binding high Z elements (e.g. the ubiquitous chlorine)
- The prohibition of direct skin contact with anything destined to go in the vacuum system

Vessel Conditioning

- Routes to a high vacuum standard

- The baking of components of the vessel itself during manufacture (e.g. to 400°C)
- The baking of everything that goes inside the vessel to whatever temperature it will tolerate (e.g. 200°C)
- The specification and preservation of mirror-bright interior surfaces (perhaps including electropolishing the vessel interior surfaces)
- The avoidance, or protection of, plastics to which the plasma has a line of sight

Cf. Materials like stainless steel, inconel or aluminium stay clean because they form very thin stable oxide layers which inhibit further atmospheric corrosion

→ The oxides readily reduced by energetic hydrogen

Vessel Conditioning

- Glow discharge cleaning after baking at ~ 15 $\mu A cm^{-2}$

- In hygrogen (creating water which is pumped away): loading the vessel with hydrogen
- In methane (or methane-hydrogen, etc.) to create a graphitic of carbide layer smothering any oxides, etc.: loading the walls with hydrogen
- In helium to get the hydrogen out (the helium diffuses out subsequently since it is chemically inert)
- In trimethyl boron $B(CH_3)^3$ to create a carbon-boron-carbide layer (apparently even better than simple carbonisation because of the lower *Z*)
- In diborane (with care since this is a highly toxic and explosive gas) to lay down a high boron content layer, claimed by some to be more effective than the trimethyl boron approach

Vessel Conditioning

- Gettering using titanium or chromium

- Ti, Cr having a strong affinity for oxygen and many other impurities and an almost magical effect on the plasma behaviour even in a dirty system with a natural base pressures above about 5×10^{-7} torr of H_2O+CO+various hydrocarbons
- Gettering over a large fraction of the vessel interior to a thickness of about a monolayer every shot or so

- Long term disadvantages such as coating over windows and flaking of loose titanium

Vessel Conditioning

- Pumps

	Advantages	Disadvantages
Diffusion pump	- Fairly cheap - Available in many size	- Backstream oil vapour cooling baffles - Liquid nitrogen cold traps need to be added resulting in undesirable system complexity
Cryopump	- High pumping speed	- Expensive - Operational problem such as spontaneous dumping if over loaded
Getter pump	- Good performance with very simple installation requirements (just a local heater to regenerate the active surface)	- Limited lifetime

- Diffusion and TMPs are generally backed by mechanical pumps: 450 torr l s^{-1} TMPs backed by a 400 m^3h^{-1} Rootes pump and a 40 m^3h^{-1} rotary pump used in a typical small machine