Vacuum Science and Technology in Accelerators

Ron Reid

Consultant

ASTeC Vacuum Science Group

(ron.reid@stfc.ac.uk)

Session 6

Components, Construction and Processing Techniques for Vacuum Systems

Aim

- To examine constructional techniques of particular relevance to vacuum performance.
- To understand why some standard vacuum components are designed in the way that they are.
- To understand why we need to adopt a rigorous cleaning and processing strategy for modern accelerators
- To understand some of the techniques involved

Vacuum Seals

Every accelerator incorporates many demountable vacuum joints. Clearly these have to be reliable.

The seal is the most unreliable part of such joints.

Seals are made of elastomers or metals.

The requirements are that the seal is deformable, elastic and stable.

In accelerators, radiation resistance of seal materials can be of importance.

Elastomers

Suitable elastomers include

- Buna N
- Neoprene
- Fluoroelastomer (Viton™)
- Silicone
- PTFE
- Polyimide (Vespel™, Kalrez™)

Elastomer seals

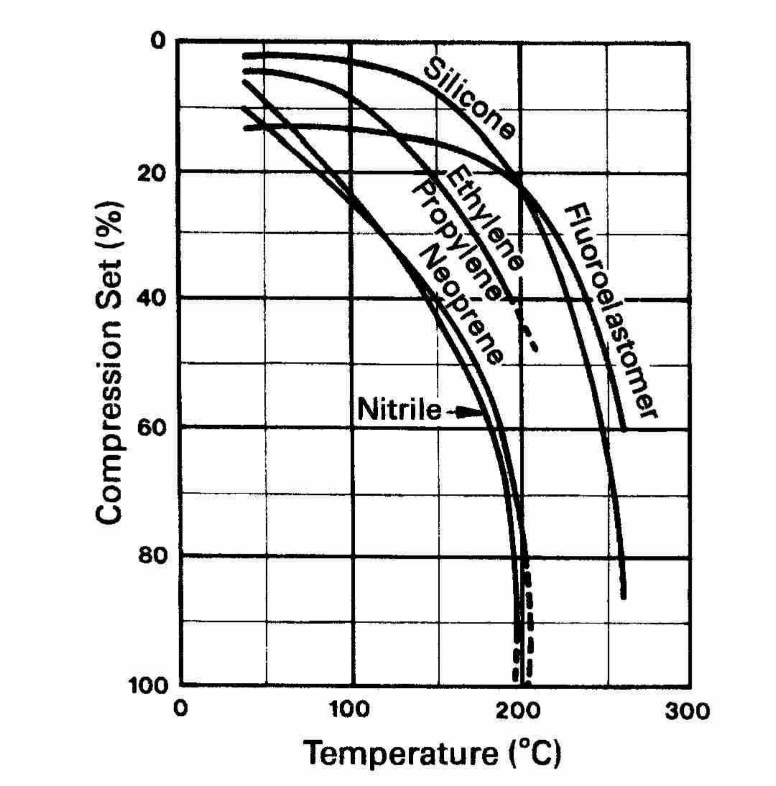
Limited temperature range

- Buna N, Neoprene ~ 85°C
- Viton ~ 150°C
- Polyimide, PTFE ~ 275°C

Limited radiation resistance

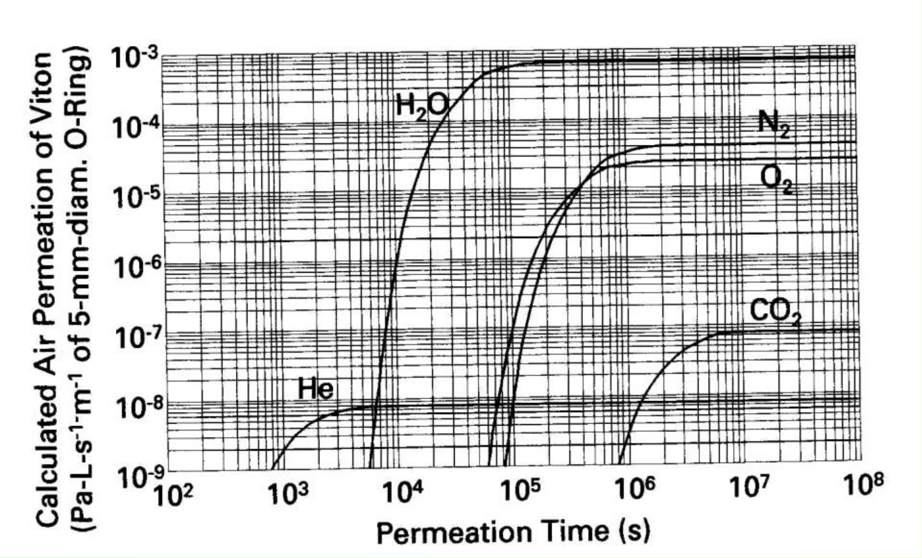
- PTFE – poor
- Viton – moderate
- Polyimide - reasonable

Elastomers

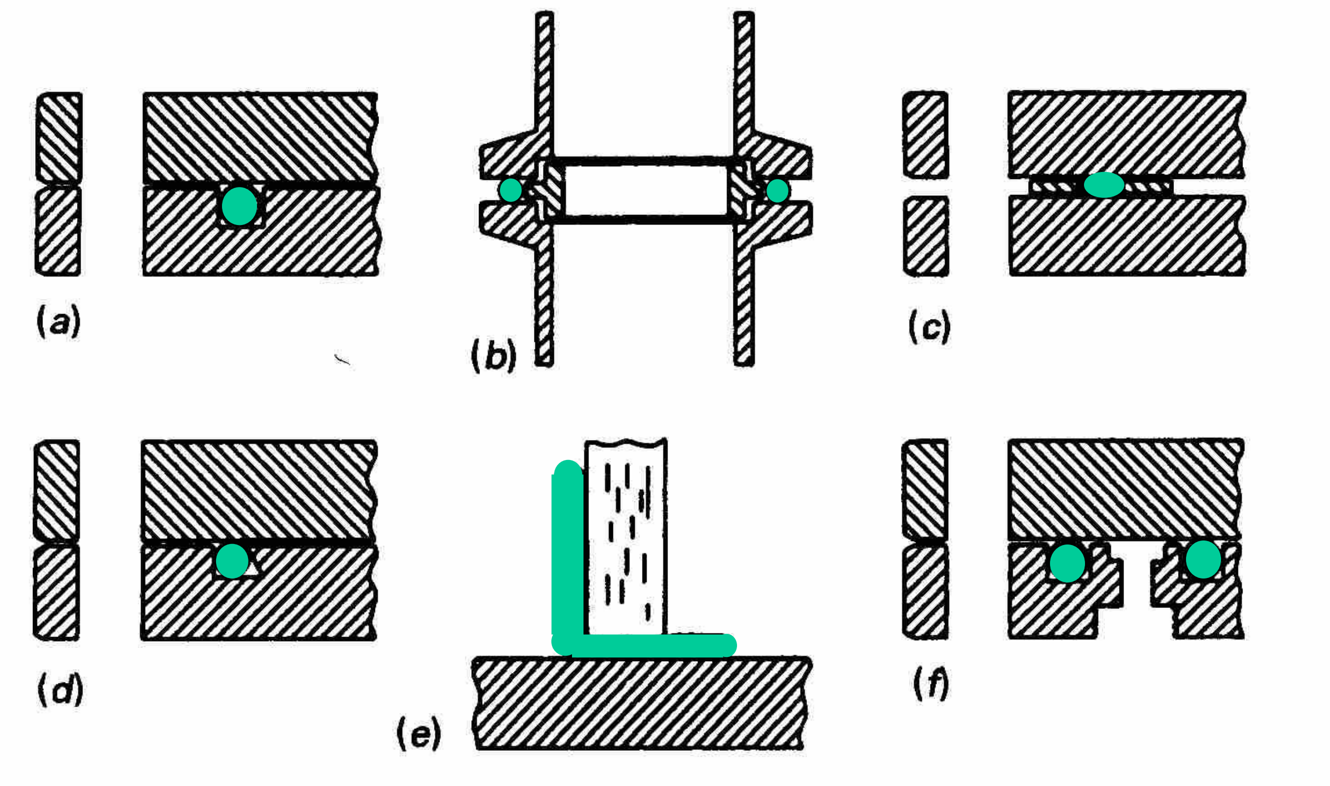


Compression set

Permeation



Elastomer seal configurations



Metal Seals

Copper

Gold

Aluminium

Tin

Indium

Metal Seals

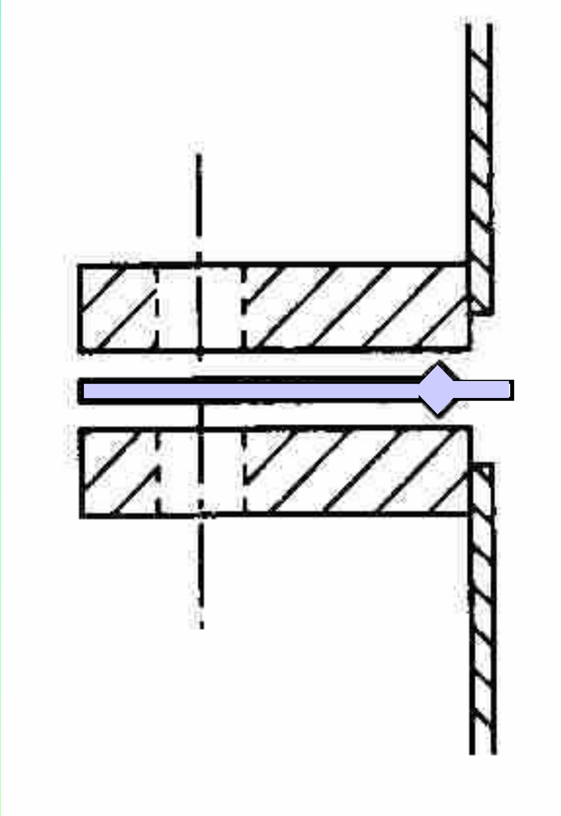
Metal O-rings (usually called wire seals) can be used in the same configurations as elastomer seals (except "L" seals) when higher temperatures are required.

In addition, there are three important types of seal

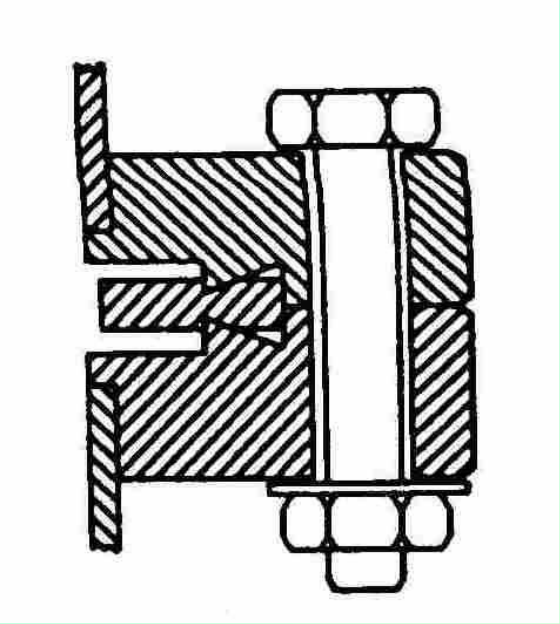
- "Diamond"
- Knife-edge
- Helicoflex^{TM}

Metal Seals

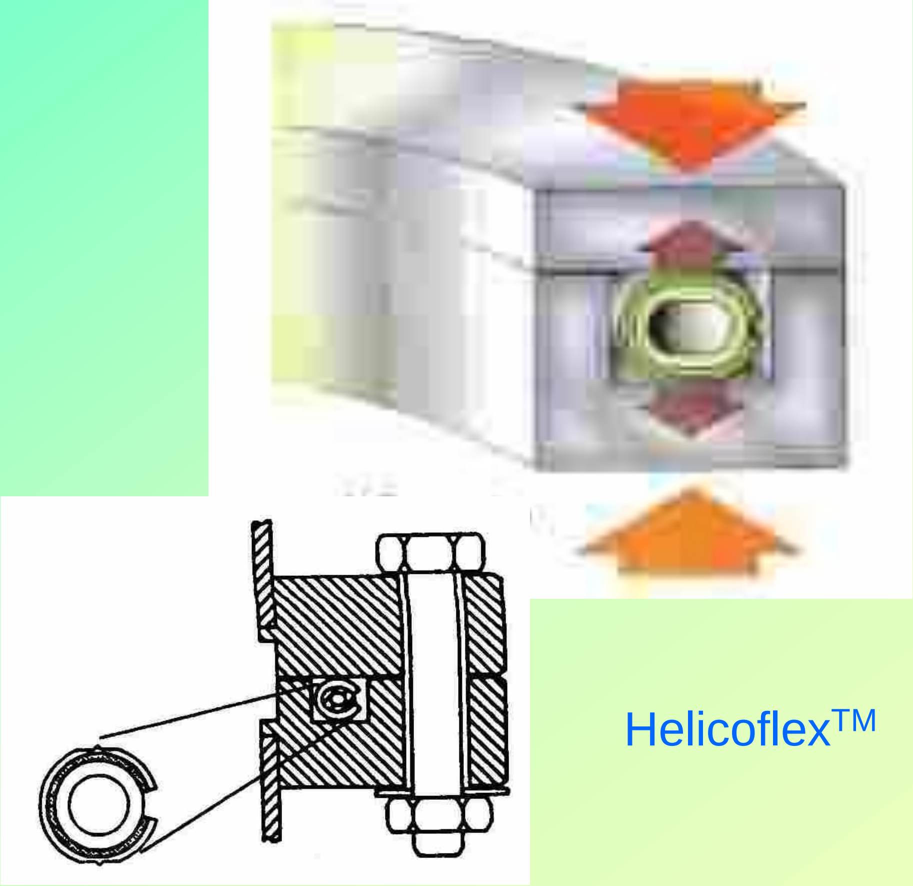
Diamond seal



Metal Seals

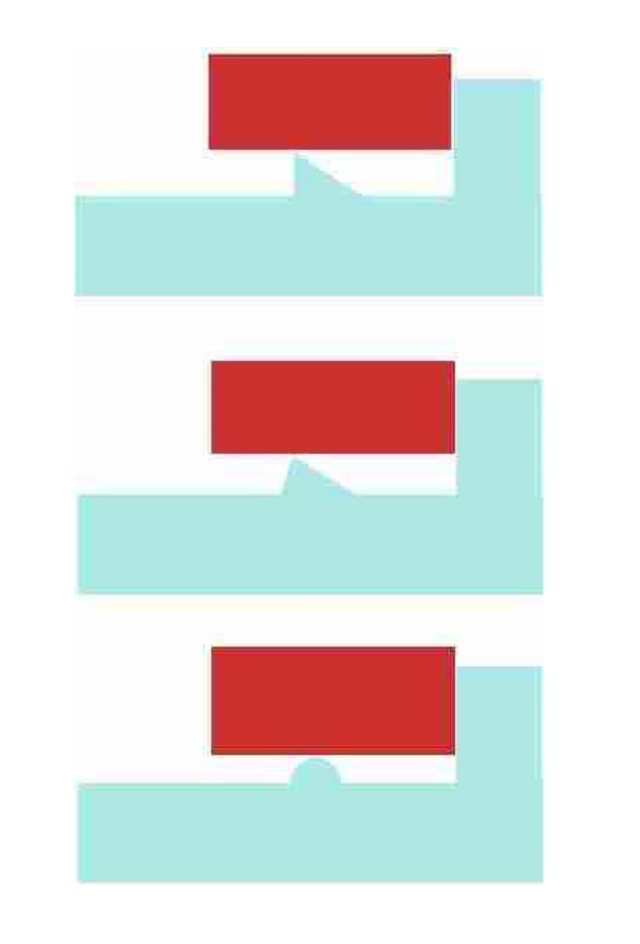


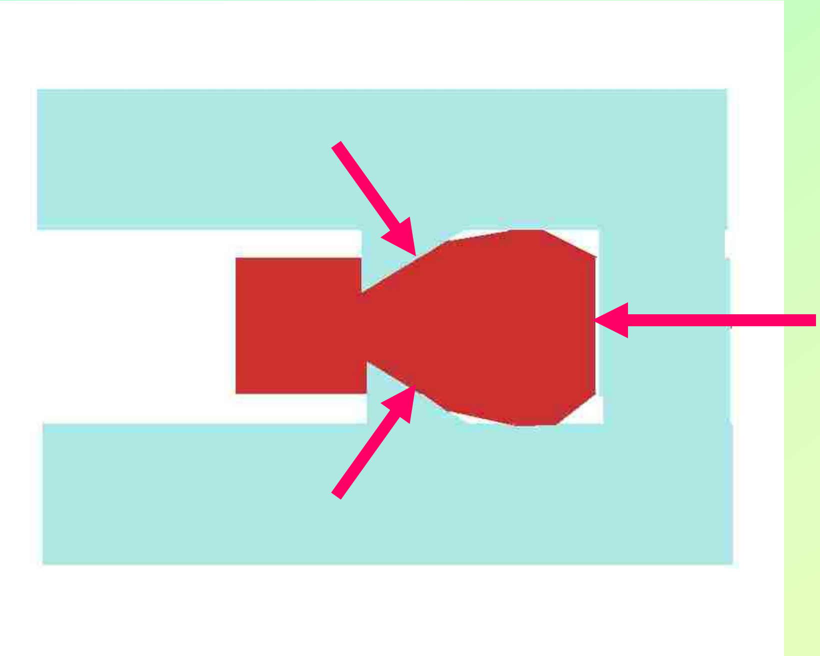
Knife edge - Conflat^{TM}



Helicoflex^{TM}

Knife edge seals





Metal Gasket Material

“Copper”

- OFHC
- OFS (0.1% Silver)
- Silver plated

Helicoflex

- Many different metal sealing jackets available

Flanges

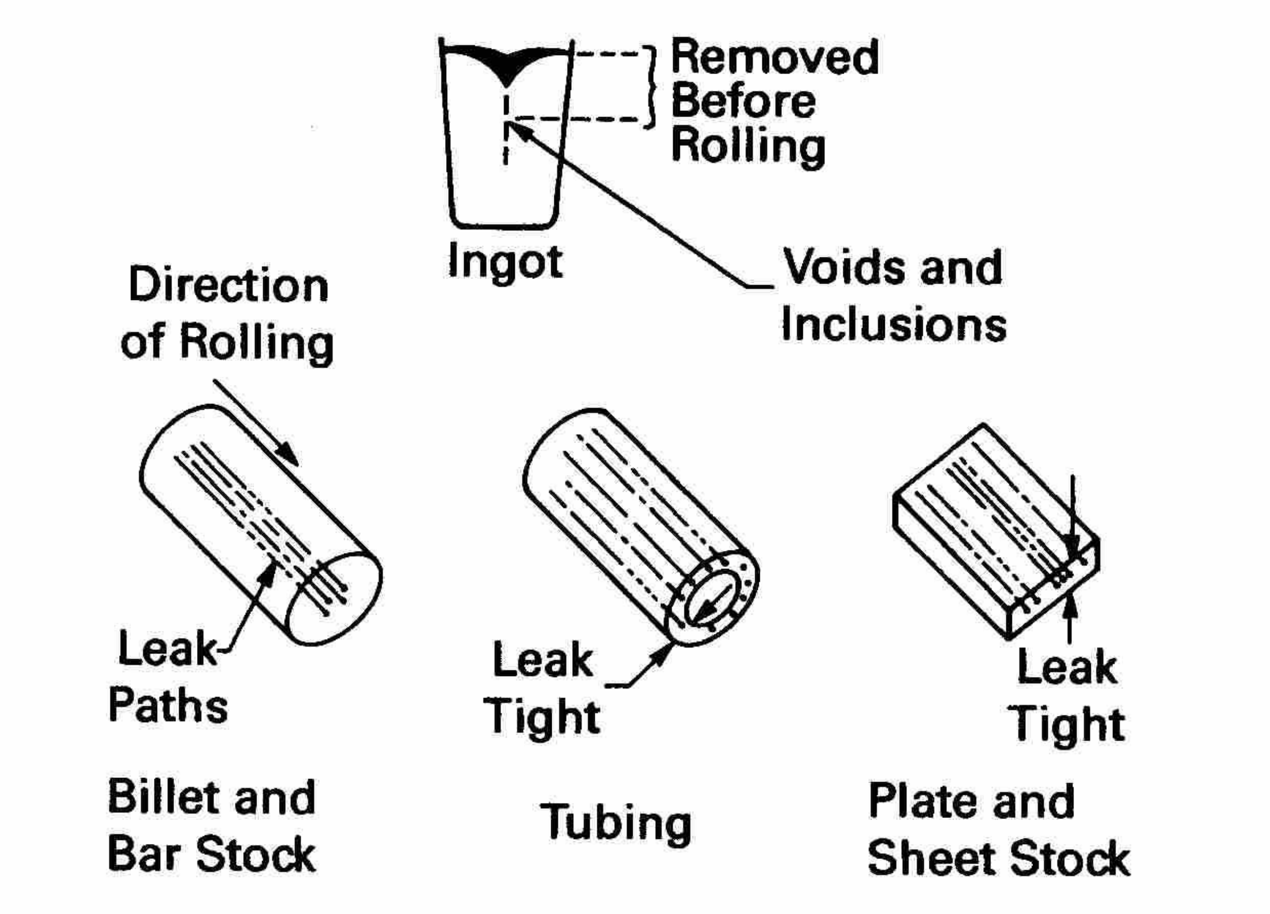
Material as for vessel construction

- Harder than seal
- For wire and diamond seals, roughness should be ~ 1μ
- Lap finish should be parallel to the seal run

Knife edge (“Conflat™”) flanges

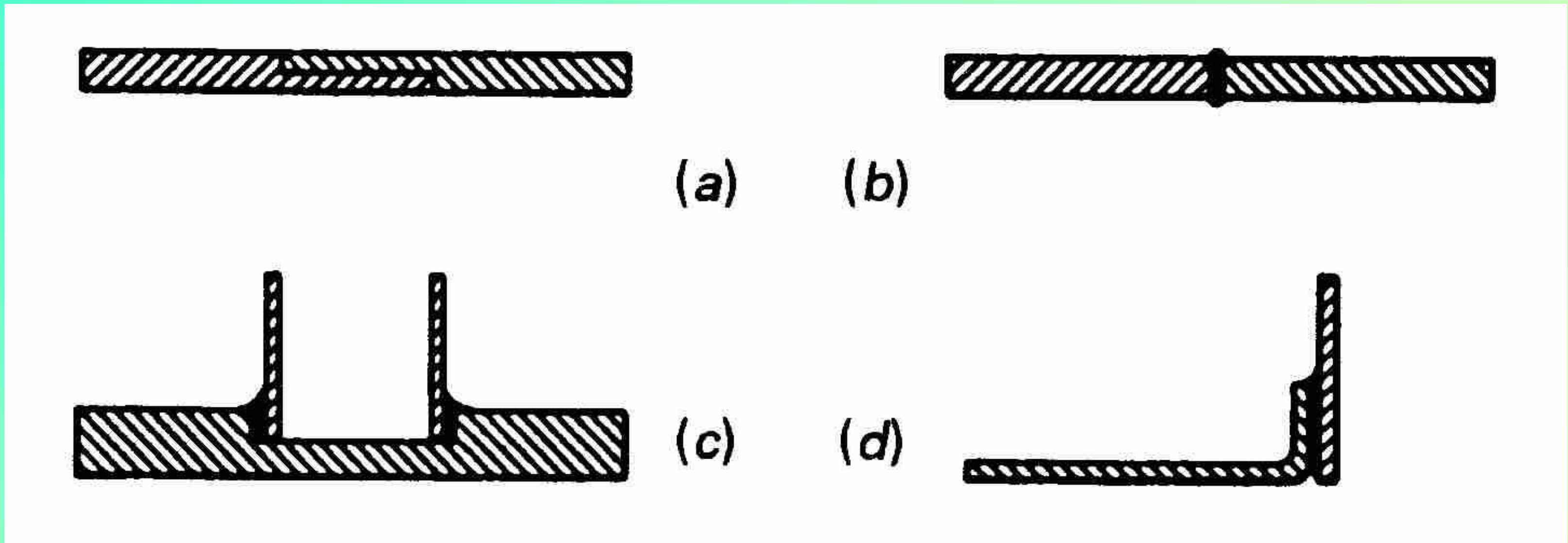
- N hardened aluminium
- 304 or 316 Stainless steel
- For highest reliability, 316LN should be used

Metal Stock


Removed
Before
Rolling
Ingot
Voids and
Inclusions
Direction
of Rolling
Leak
Paths
Leak
Tight
Leak
Tight
Billet and
Bar Stock
Tubing
Plate and
Sheet Stock

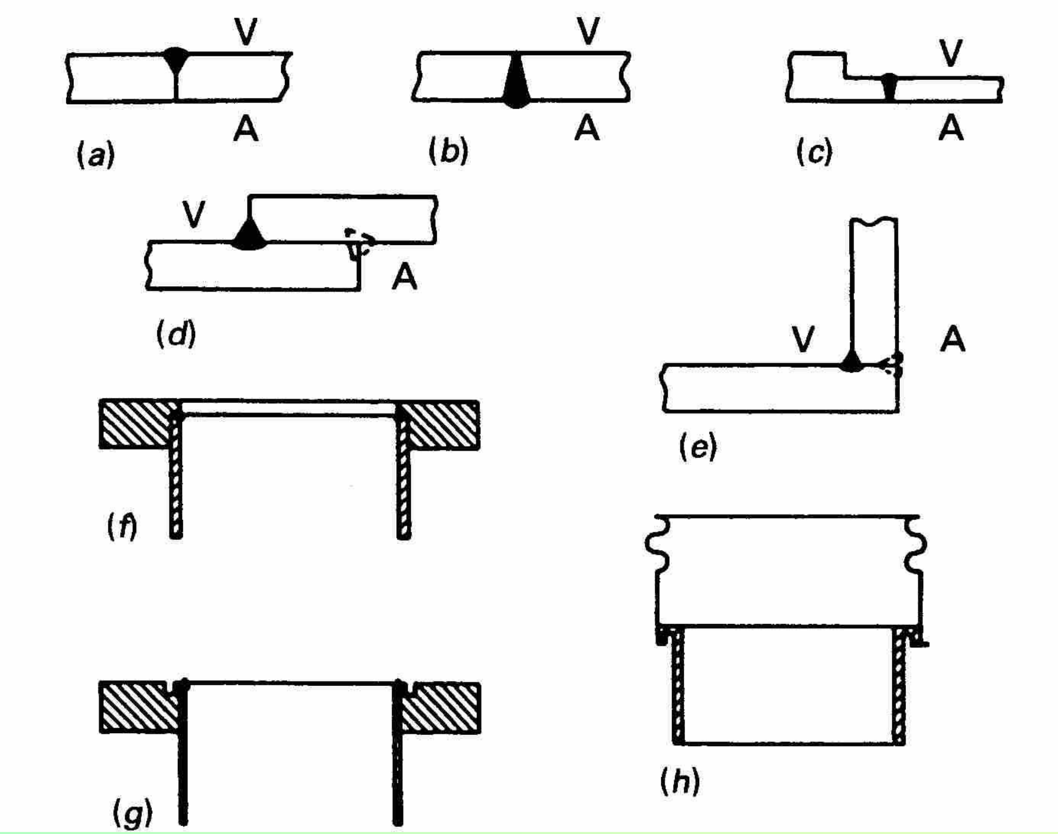
Construction Techniques

Brazing

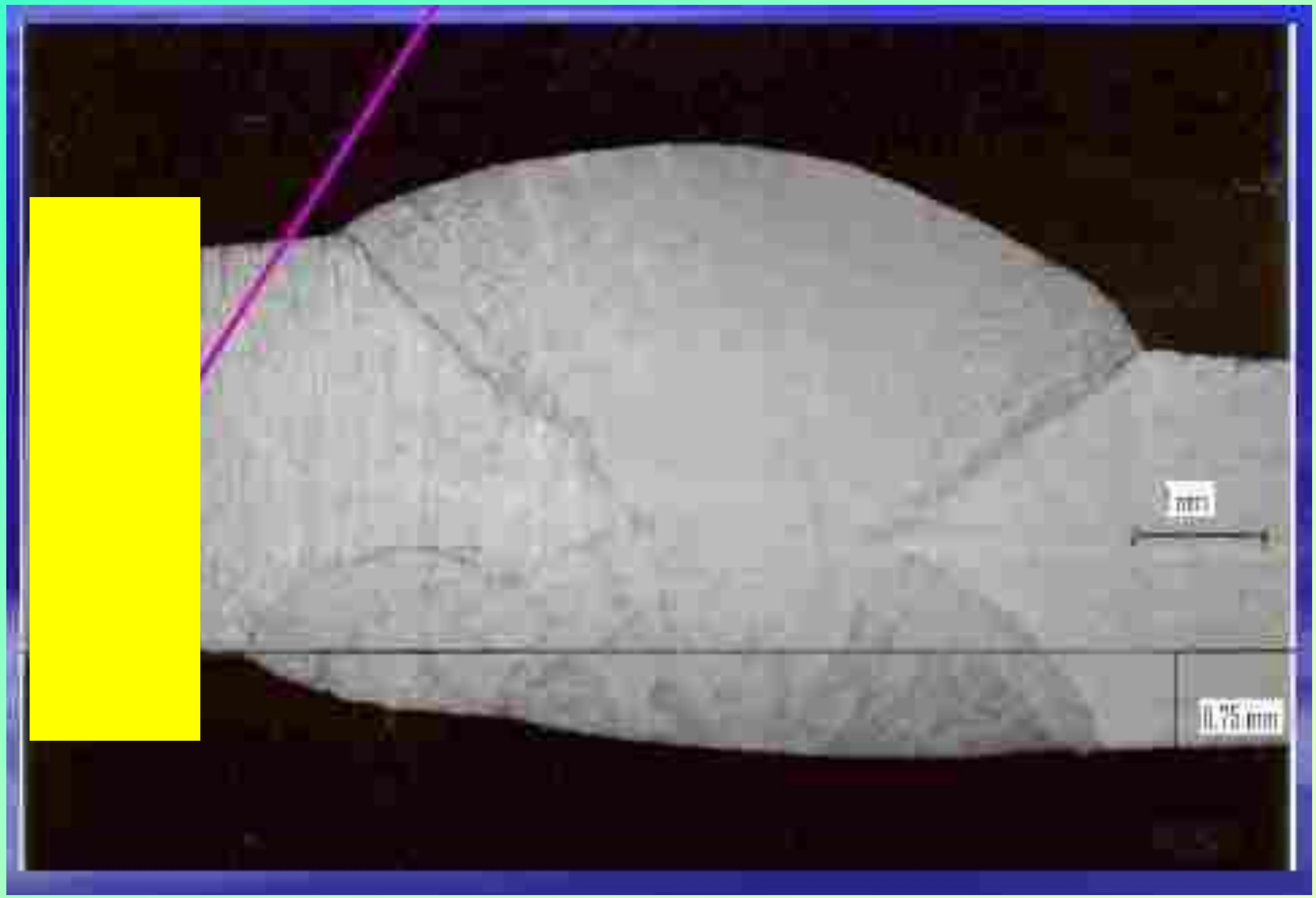


Construction Techniques

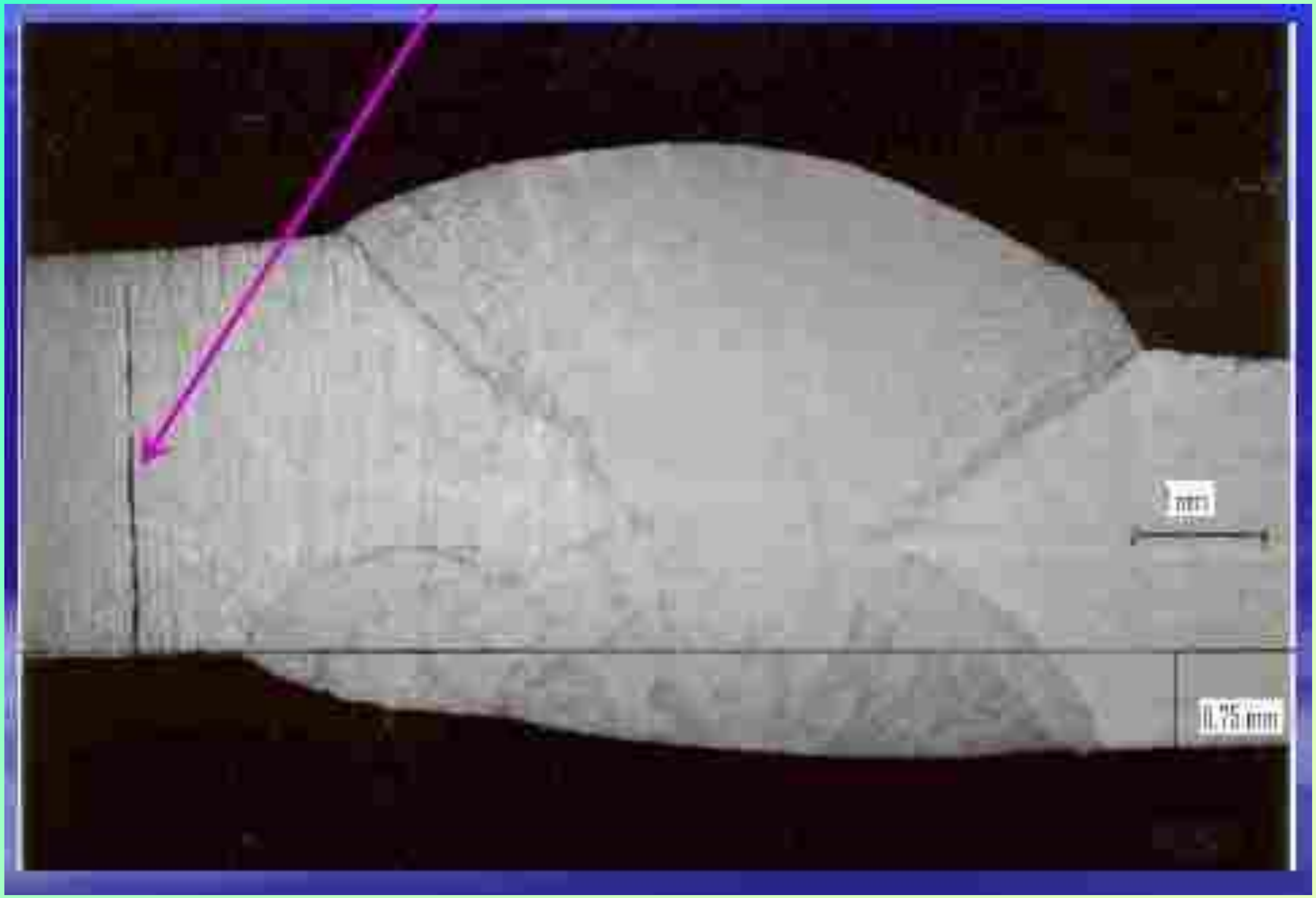
Welds



Construction Techniques

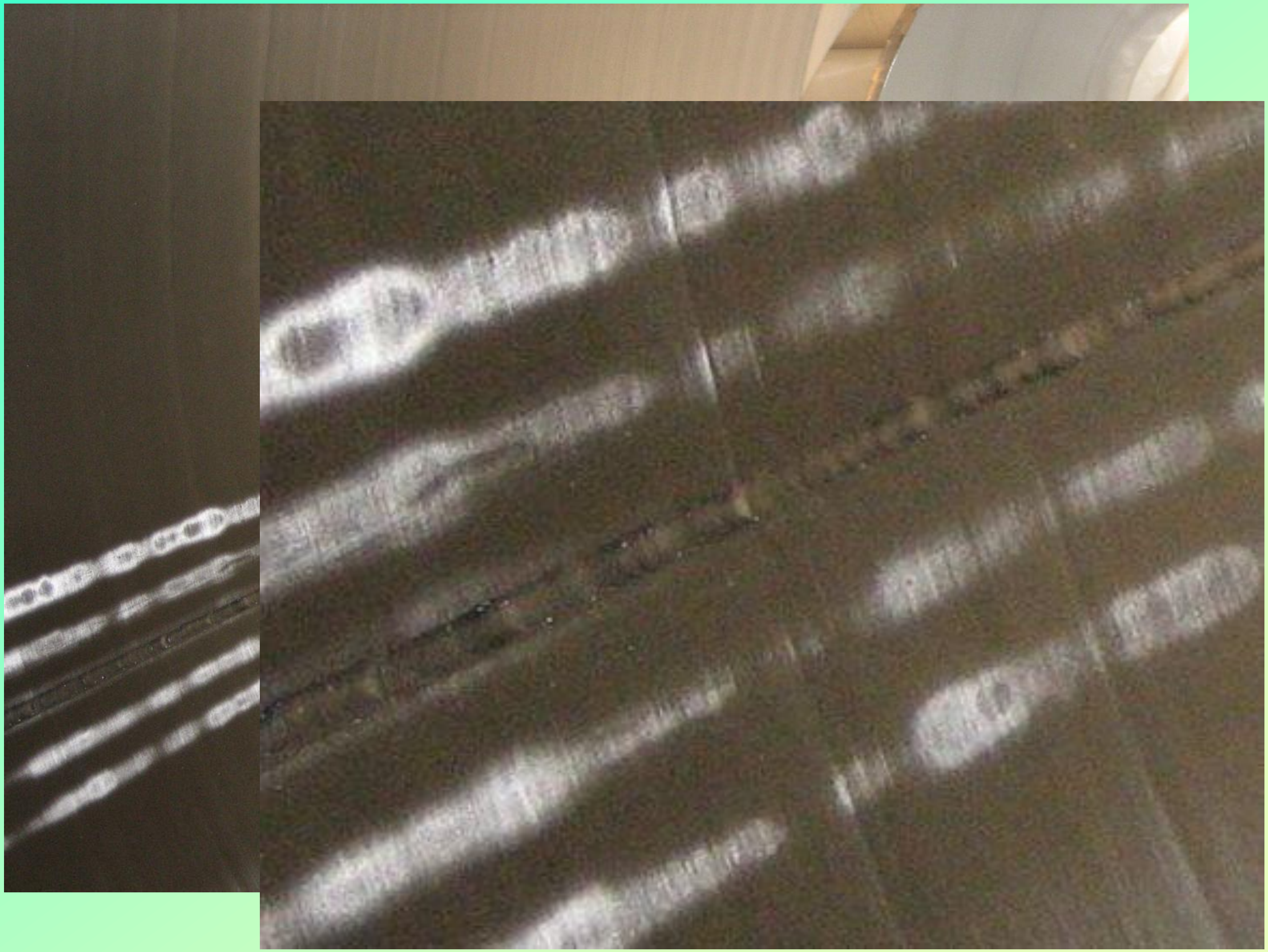


Construction Techniques

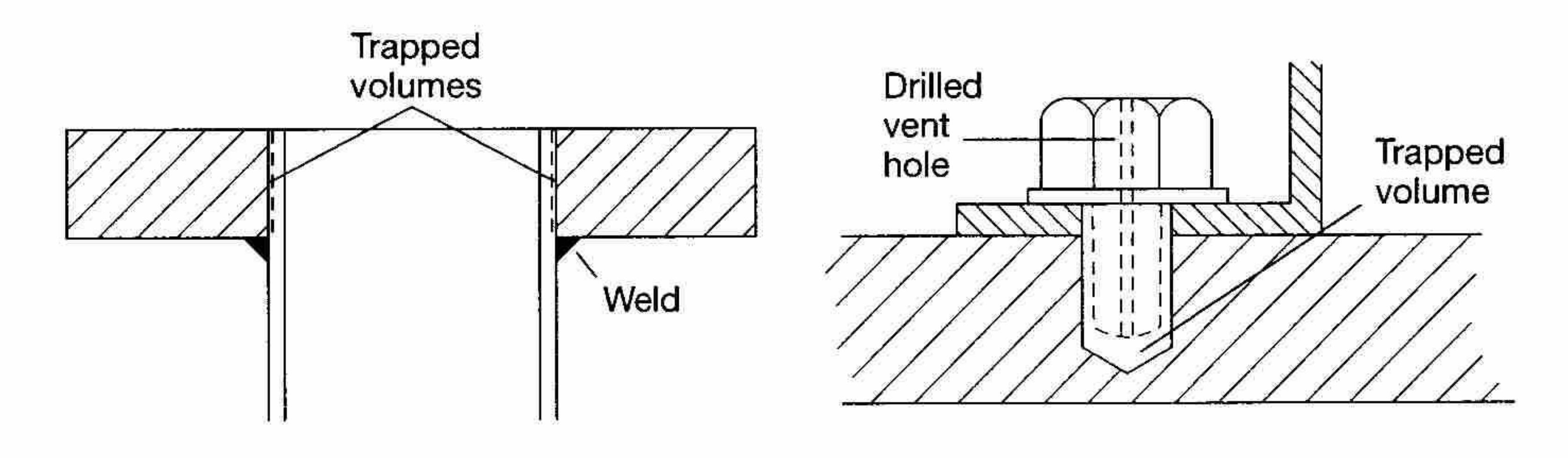


Construction Techniques

Construction Techniques

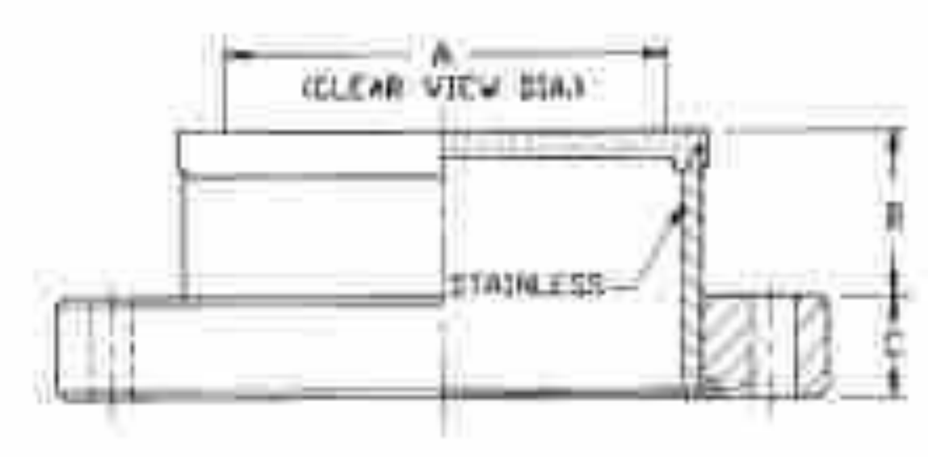


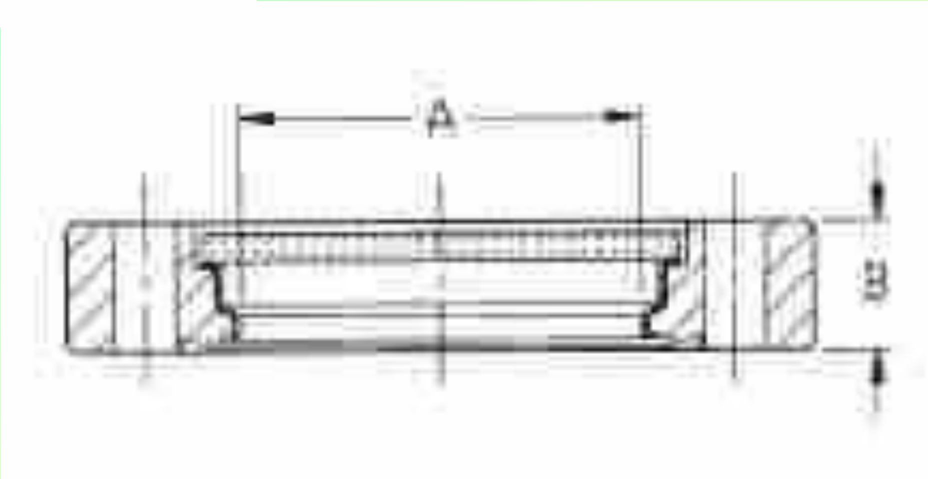
Construction Techniques



Components

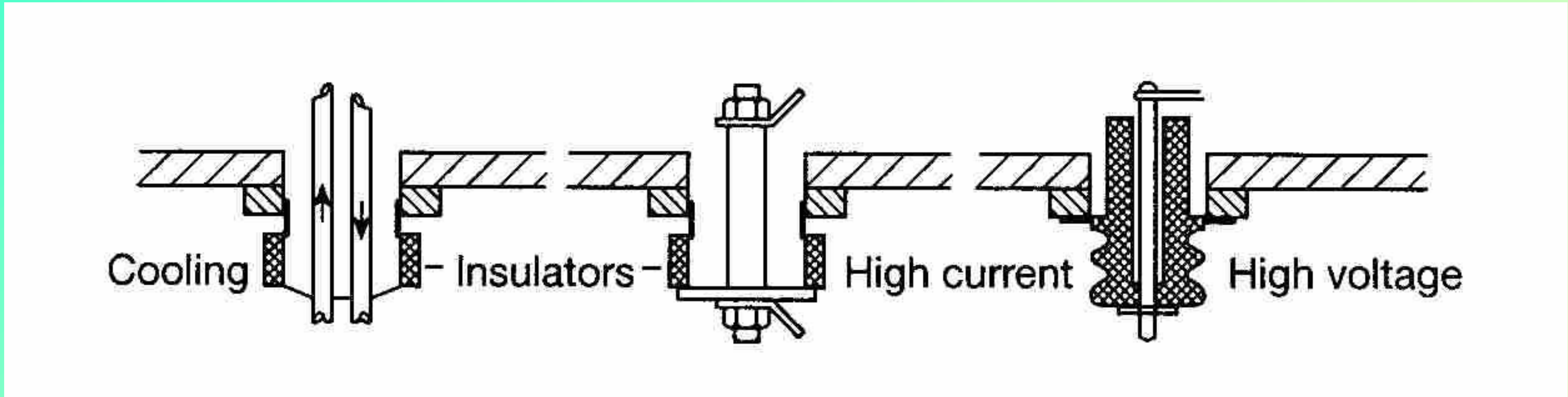
Windows (Viewports)





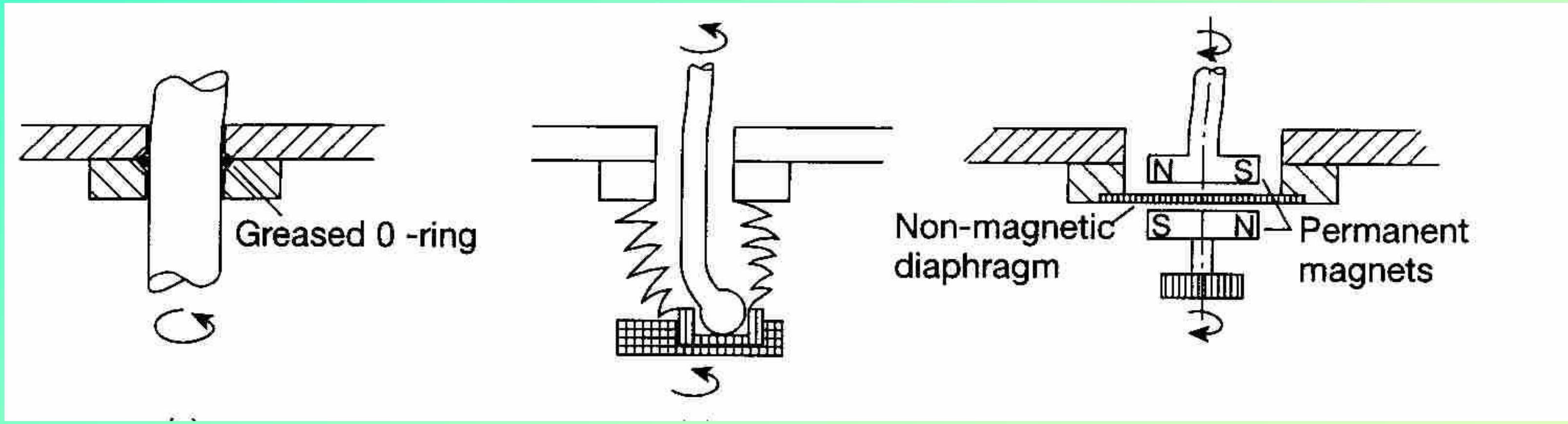
Components

Feedthroughs



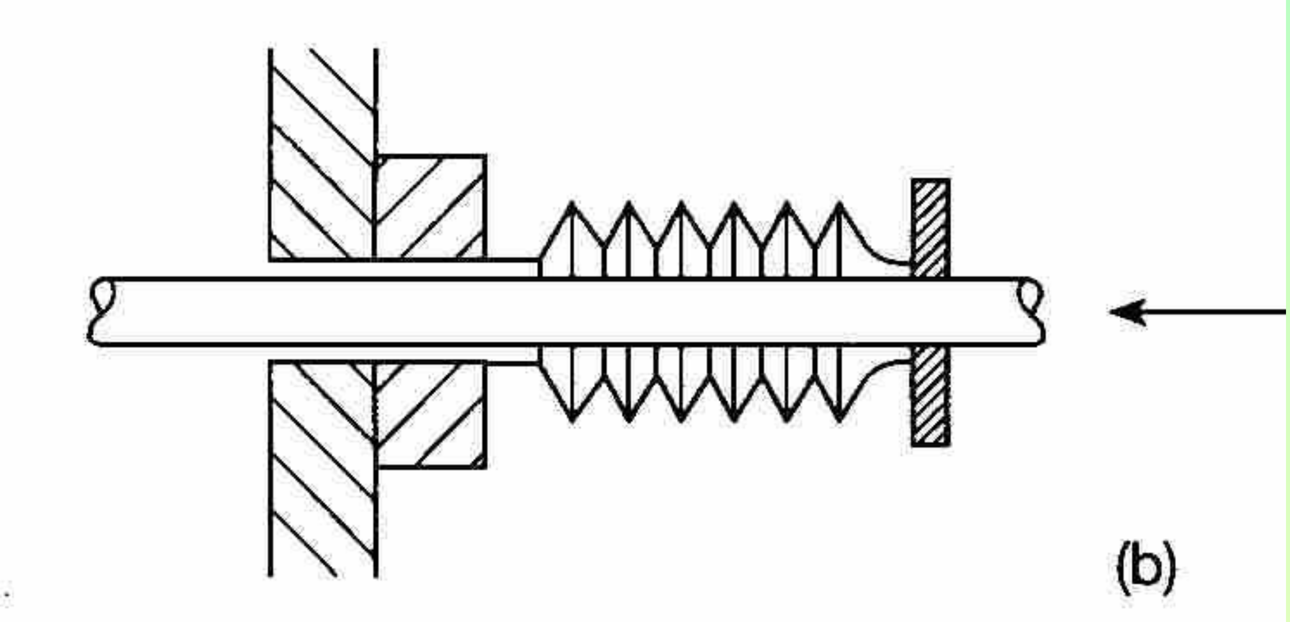
Components

Motions (Rotary)



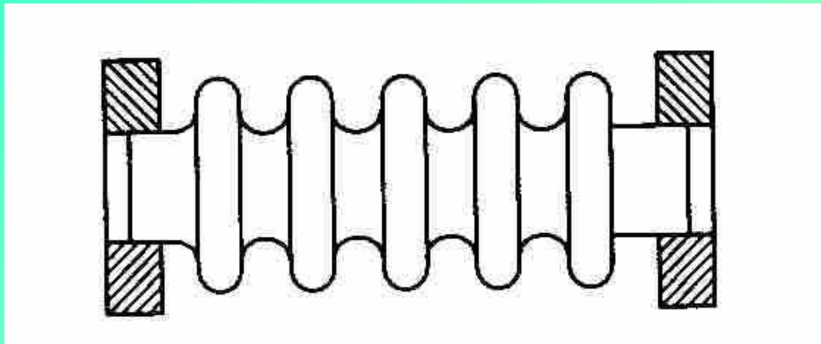
Components

Motion (Linear)



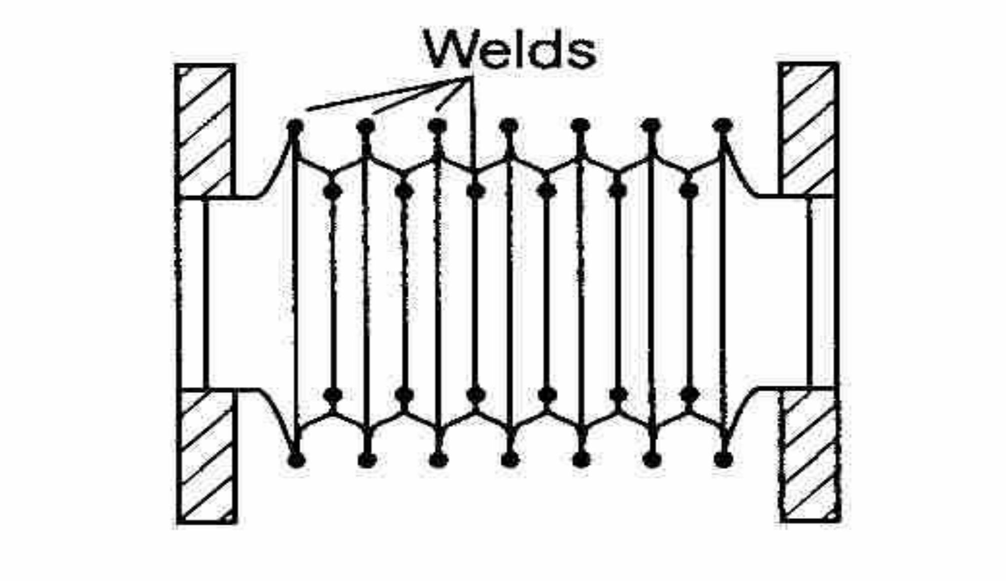
Components

Bellows



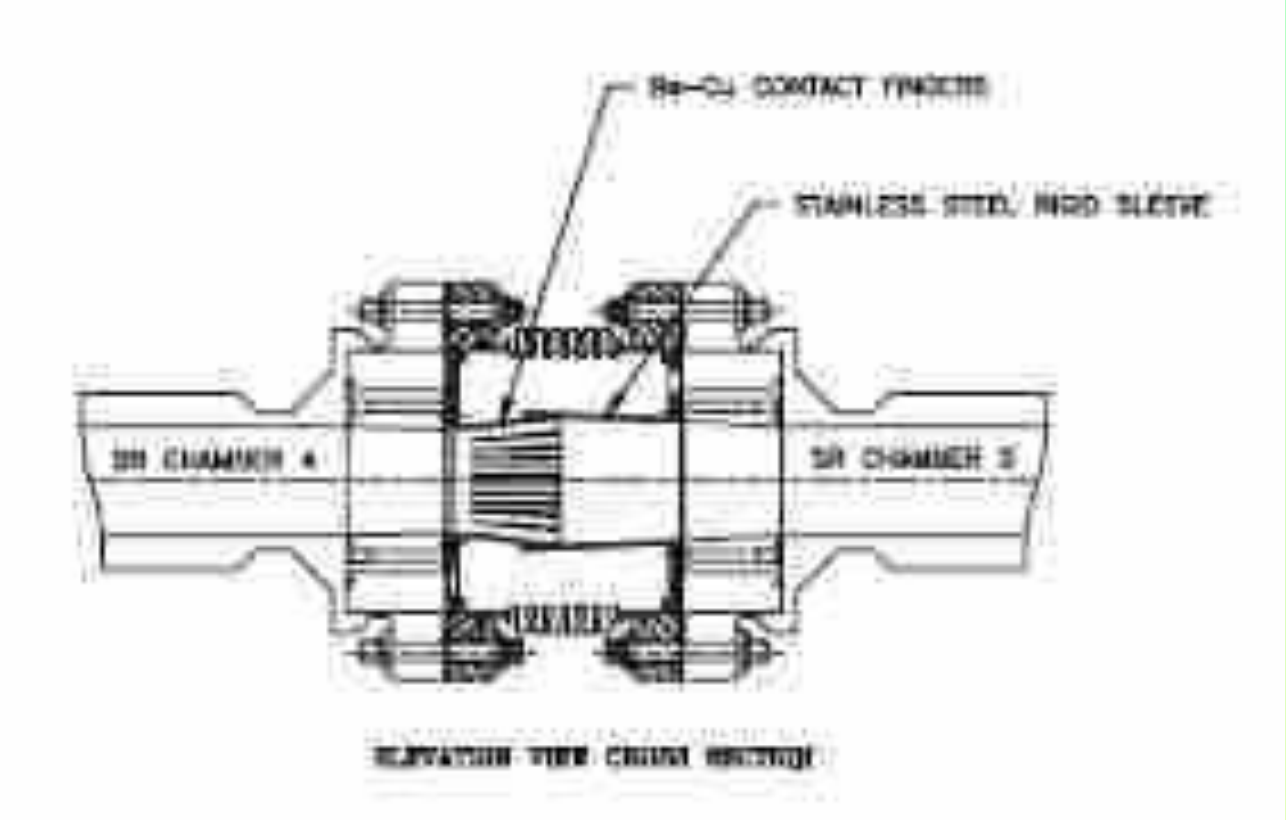
Formed

Edge welded



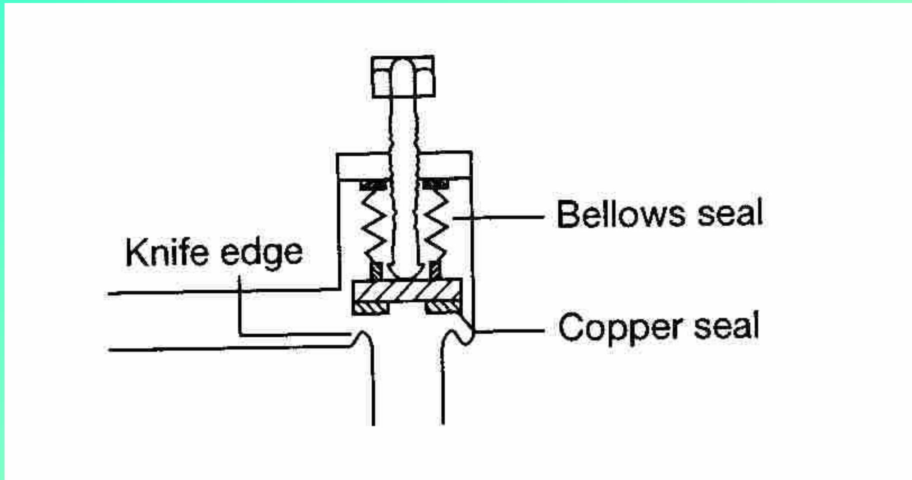
Components

Shielded Bellows

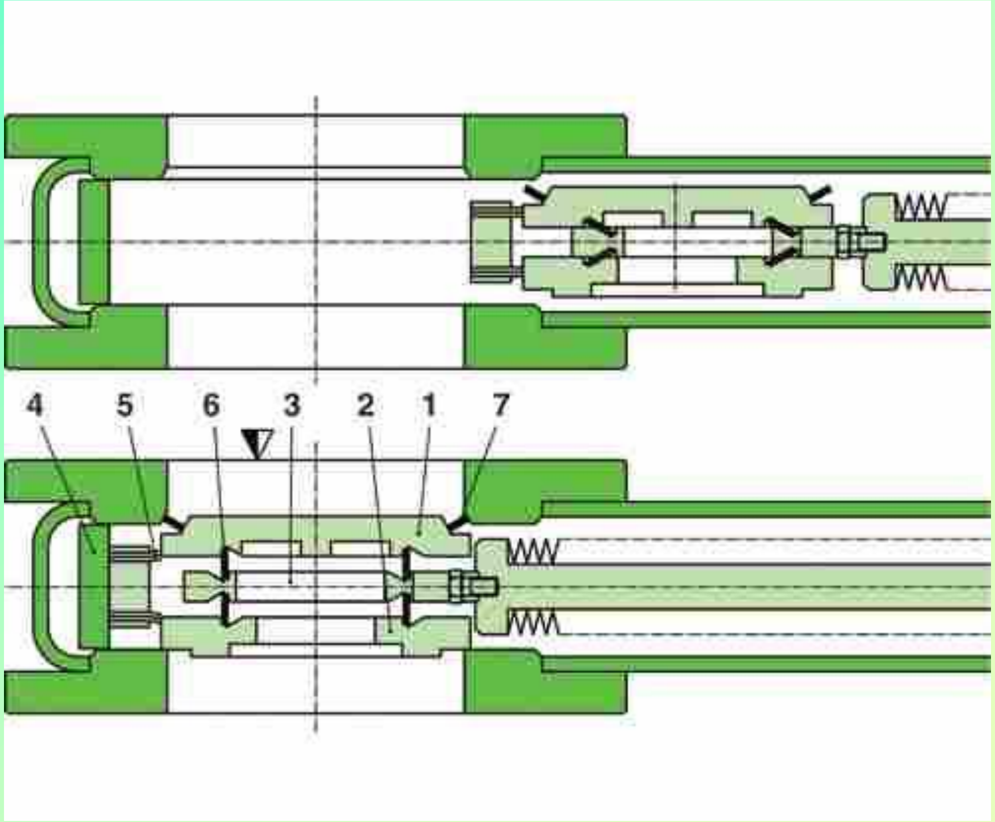


Basic Vacuum Design of Accelerators Components

Right Angle Valve

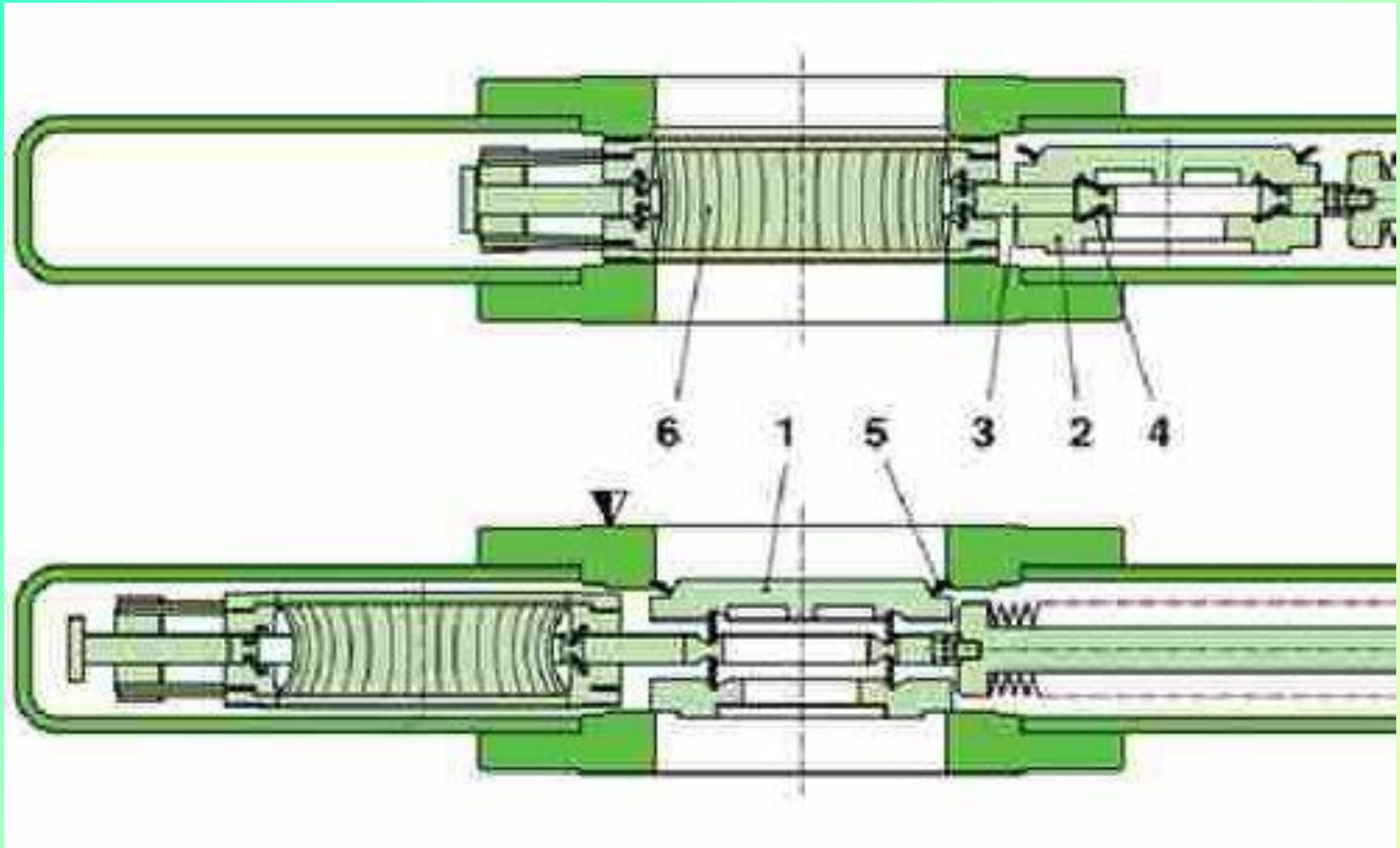


Gate valve



Components

RF Shielded Gate Valve



Lubrication

Lubricants may be required for bearing surfaces, especially in UHV where cold welding can occur.

Moving surfaces in contact should be designed so that the possibility of galling or scraping is minimised.

Lubricants should be chosen so that the vapour pressure is sufficiently low e.g. ptfe greases, Fomblin™ oil or, better solid lubricants should be used

Lubrication

Solid lubricants

- PTFE
- Graphite
- MoS_2
- Implanted Lead
- WSe_2 or WS_2

Reliability

In an accelerator there can be many moving components – valves, shutters, beam stops, scrapers, septa, beam monitors.

These are the components most susceptible to leaks and so must be designed and operated with care.

Care has to be taken regarding the generation of particulates. This can only be done by good design.

Cleaning For Vacuum

Why Do We Need To Clean For Vacuum?

We may not need to!

- It depends on what we need vacuum for
  - Vacuum regime required
    - Ultimate pressure
  - Cleanliness
- So we need to make a proper assessment of the real requirements of the application

But in general, modern accelerators require good, “clean” vacuum

Some Reasons for Cleaning

Irrespective of application - manufacturer desires attractive appearance!

Characteristics of a surface (surface properties) may be altered by ‘contamination’ at the surface.

Processes may be poisoned by ‘contaminants’

Why Clean Accelerator Vacuum Systems?

Transport of particles and EM radiation

- Loss reduction

Reduce scattered radiation for health & safety

Maintain clean in-vacuum surfaces

- Prevent particle target poisoning
- Maintain efficient optical properties for EM radiation transport

Protect gun cathodes from poisoning/degradation

To provide a controlled atmosphere

Requirements for UHV/XHV

Minimise desorption

- Remove ‘contaminants’ (i.e. components with high outgassing/vapour pressure)
- Deplete reservoirs
  - Bulk gases
  - Surface overlayers (e.g. adventitious graphite)
- Provide barriers

How do we know if a surface is clean?

Phenomenologically

- Measure outgassing (thermal desorption)
- Measure stimulated desorption (according to requirements of system)
- In each case total and partial pressure measurements useful

Characterise surfaces

- Surface analysis

Cleaning and Processing

Cleaning of accelerator components is generally only performed during the manufacturing or pre-installation programme.

Processing may be performed during manufacture or pre-installation, but may also be carried out in situ, either as part of the installation programme or periodically during operations.

A Distinction

Differentiate between

- Cleaning
  - Removal of unwanted components
- Passivation
  - Formation of barriers
  - Low sticking probabilities

Some examples of cleaning processes

Solution

- Water based
- Solvent based
  - Alcohols
  - Chlorinated hydrocarbons
  - Freons XXX
  - Hydrofluoroether
  - Non flammable ethers

Detergents

- Aqueous
- Alkaline degreasers

Etchants

- Acids
- Alkalis

A note on surface preparation

There is a temptation to polish surfaces on the assumption that if it looks nice it must be better.

But, for vacuum use

- Avoid grinding
- Shot blasting
- Mechanical polishing

Such processes drive contaminants into the surface and they can be difficult to remove.

But sometimes they may be necessary for other reasons

Some examples of passivation

Air Baking

Electropolishing

Glow Discharge

But note that **all** of these have some cleaning effect!

Another note on surface preparation

Electropolished surfaces look very nice. However, unless essential for other reasons, it is best to avoid it for vacuum use.

The polishing process involves immersion in a mixed acid solution (often containing things like orthophosphoric acid). It results in a heavily modified sub-surface layer which contains a lot of hydrogen and acid residues which can increase outgassing.

Baking at 450^{o}C is usually required to restore the initial (untreated) outgassing rate.

What strategy should be adopted?

The least that is proved to be effective for the task in hand

But understand what is required and the limitations of each process

Design for cleaning

Pay enormous attention to detail

Pay enormous attention to health and safety!

About Bakeout

Bakeout to moderate temperatures (250^{o}C) is an efficient way of reducing outgassing, especially of water.

In an accelerator, bakeout has to be undertaken with care to ensure temperature gradients are minimised and damage does not occur.

Vessel supports must be designed to accommodate the movements due to thermal expansion and contraction (and so that vessels get back to where they started!)

Bellows are used to accommodate these movements.

About Bakeout

With stainless steel, in machines the most common way to bake is to use wrapped heater tapes and bands with ceramic blanket insulation.

For simpler vessels, close wrapped Kapton insulated printed heaters with superinsulation can be used to reduce the overall thickness to less than 1mm.

For aluminium where temperatures used are less than 180^{o}C, superheated water or wrapped film are used.

About Bakeout

Bakeout is best performed into external pumps, e.g. turbo pump sets.

Towards the end, during cooldown, hot filament gauges should be degassed, *in situ* TSPs and NEG pumps carefully degasssed and conditioned and ion pumps “flashed” for conditioning.

Bakeout should be *monitored* rather than for fixed times – terminating when water in the rga spectrum falls to a predefined level.

Heating and cooldown rates must be carefully controlled.