Lecture 17
Cryogenic Equipment

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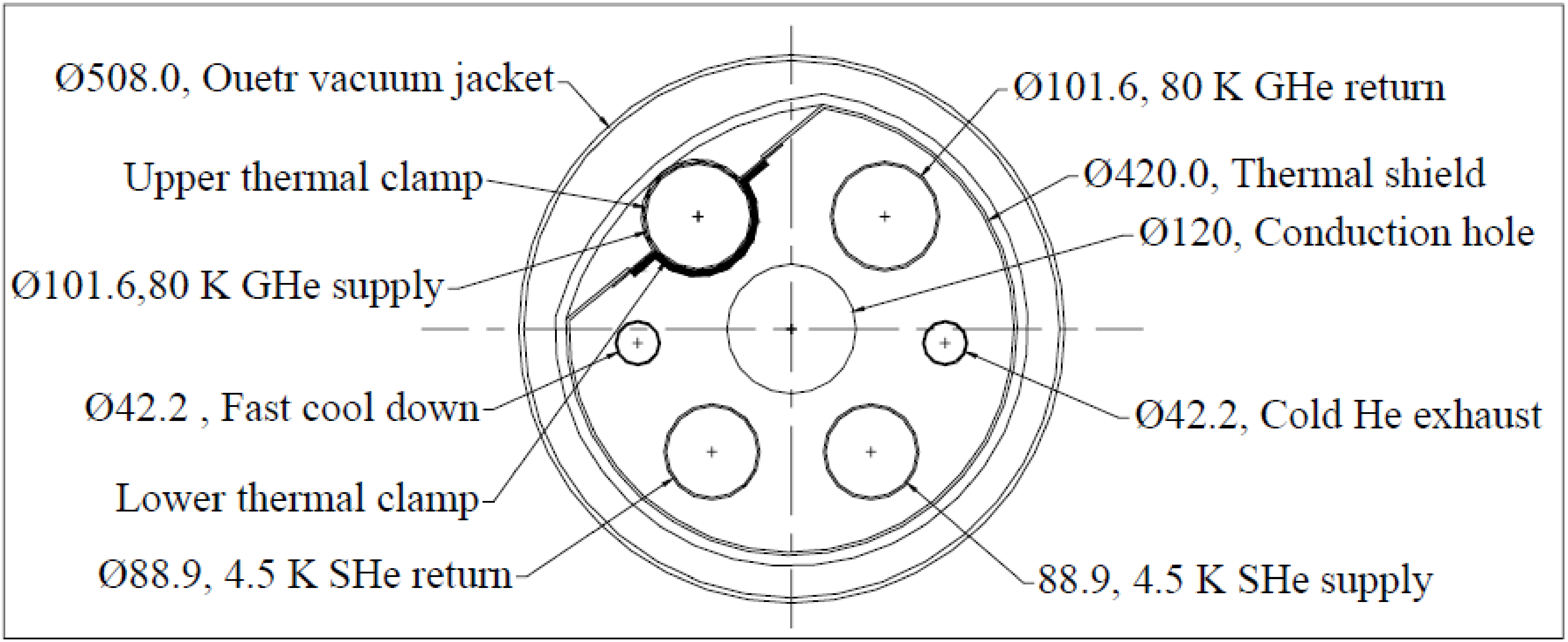
Goals

- Describe the nature, performance and design considerations of various components found in cryogenics
  - Transfer Lines
  - Connections
    - Bayonets
    - Flanges
  - Valves
- Discuss the nature of Thermal Acoustic Oscillation and techniques for avoiding it

Transfer Lines

- Vital part of a cryogenic system
  - Transfers cryogenic fluids between components
  - Essentially a long cryostat
  - Can be a significant part of system cost and heat leak
  - Can be acquired commercially or custom built
- Key design issues
  - Thermal contraction (significant due to long lengths)
  - Heat Leak (use of active thermal shields)
  - Forces generated by fluid pressure, thermal contraction must be managed so as to not impact alignment of components
  - Vacuum integrity (pump outs and relief valves)

Transfer Line Example ITER



"Design, Analysis and Test Concept for Prototype Cryoline of ITER"
B. Sarkar et. Al
Adv. Cryo. Engr. Vol 53 (2008

Transfer Lines

- Methods to address thermal contraction
  - Rigidly fix interior pipes to vacuum shell and install bellows on vacuum shell and on all pipes
  - Install bellows on cold pipes only
  - Use bends to allow interior pipes to contract
  - Use Invar pipes to reduce amount of thermal contraction (CERN/LHC)

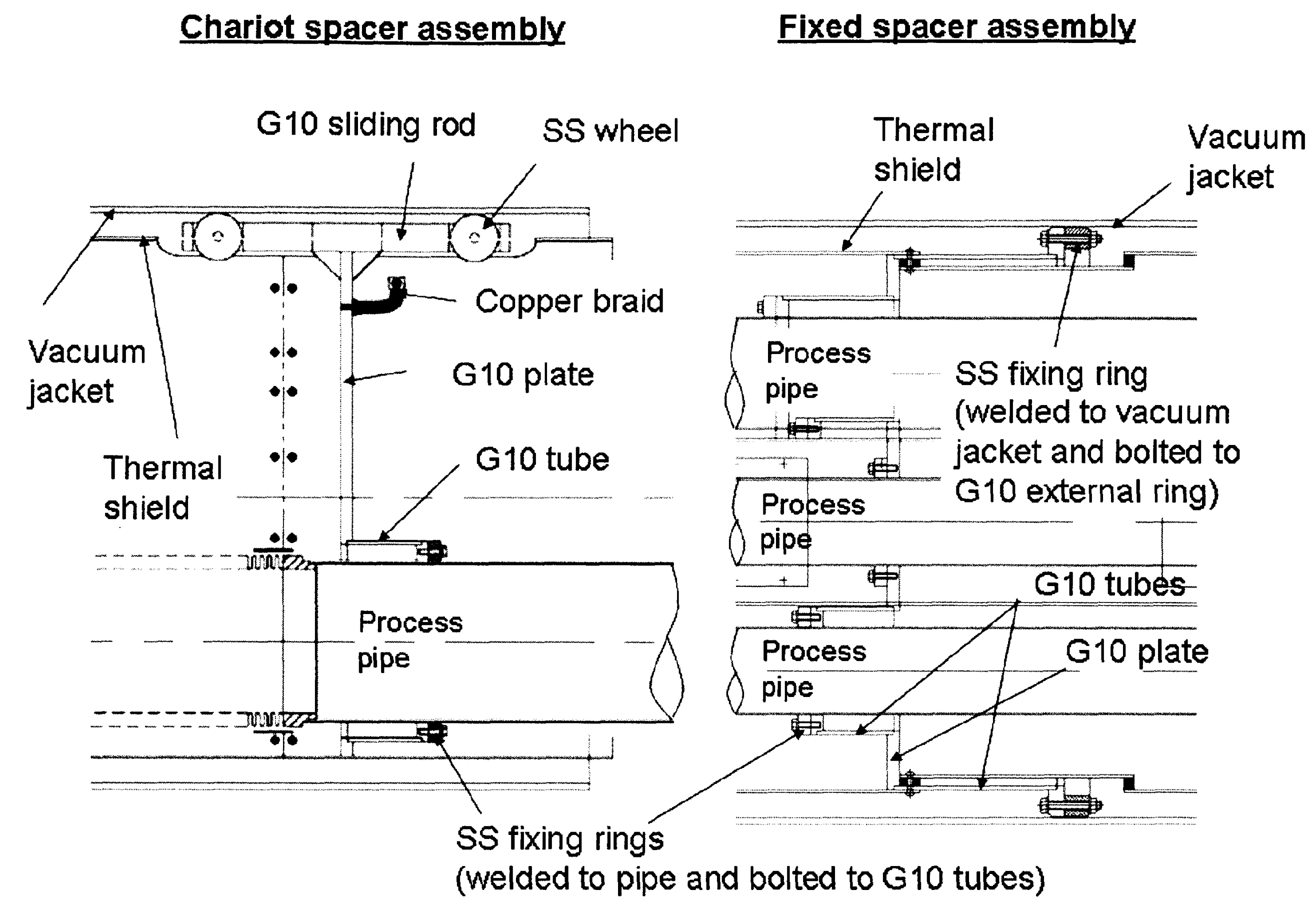
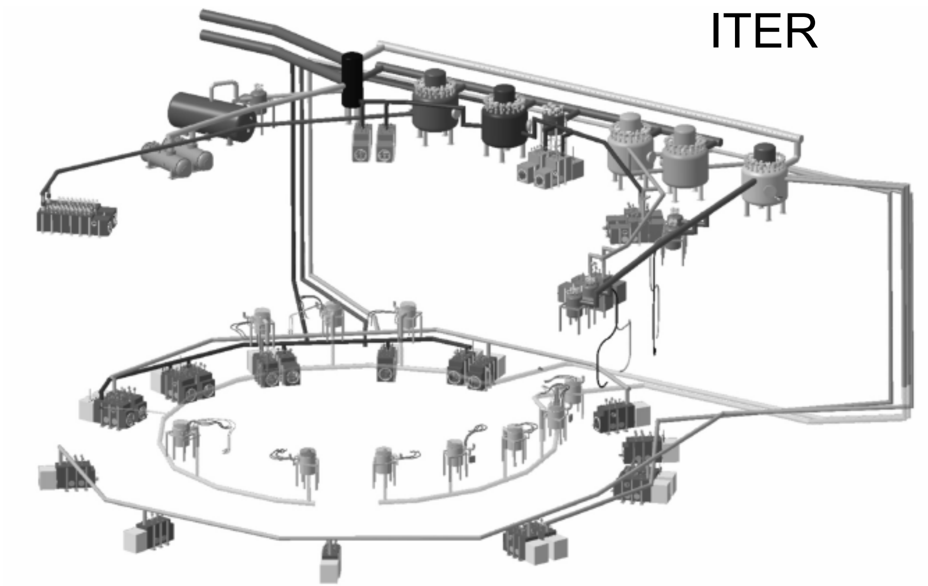


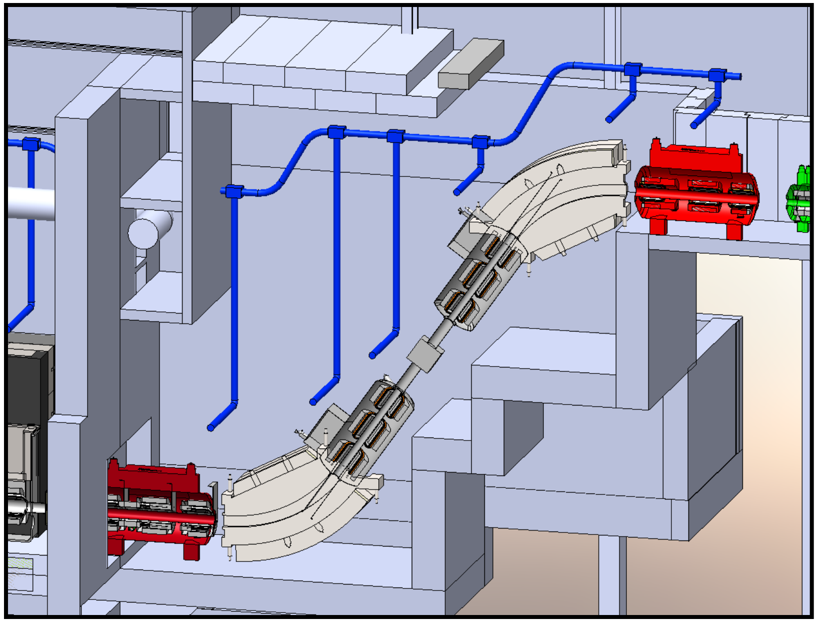
FIGURE 3. Internal supports assemblies.

Complicated Transfer Lines Become Distribution Systems

ITER



FRIB



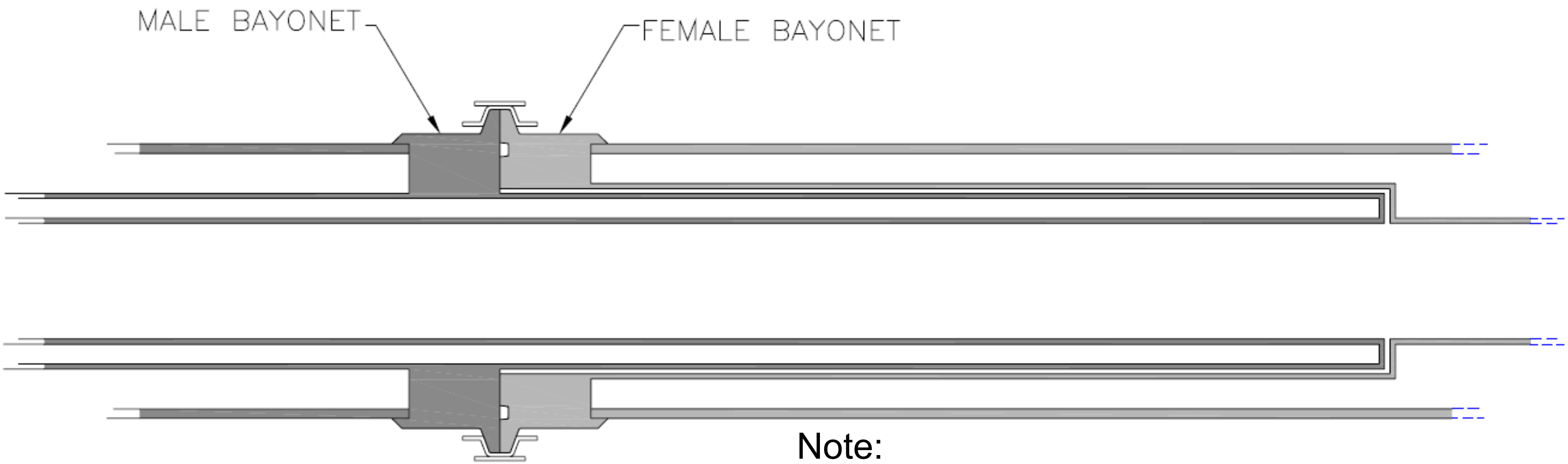
Transfer Lines

- In some cases, commercially produced transfer lines are the solution
- Nexans flexible, multiple flow transfer line

Bayonets

- Demountable piping joints that allow quick connections of cryogenic lines
- Very useful in connecting to replaceable cryogenic liquid supplies. Frequently used in "U-Tubes"
- Reentrant, low heat leak design
- Uses at least one 300 K gas seal and sometimes a cryogenic liquid seal (typically Teflon)
- Must be built to tight mechanical tolerances
- Receiving end must be lower or at least horizontal to delivery end to avoid convection

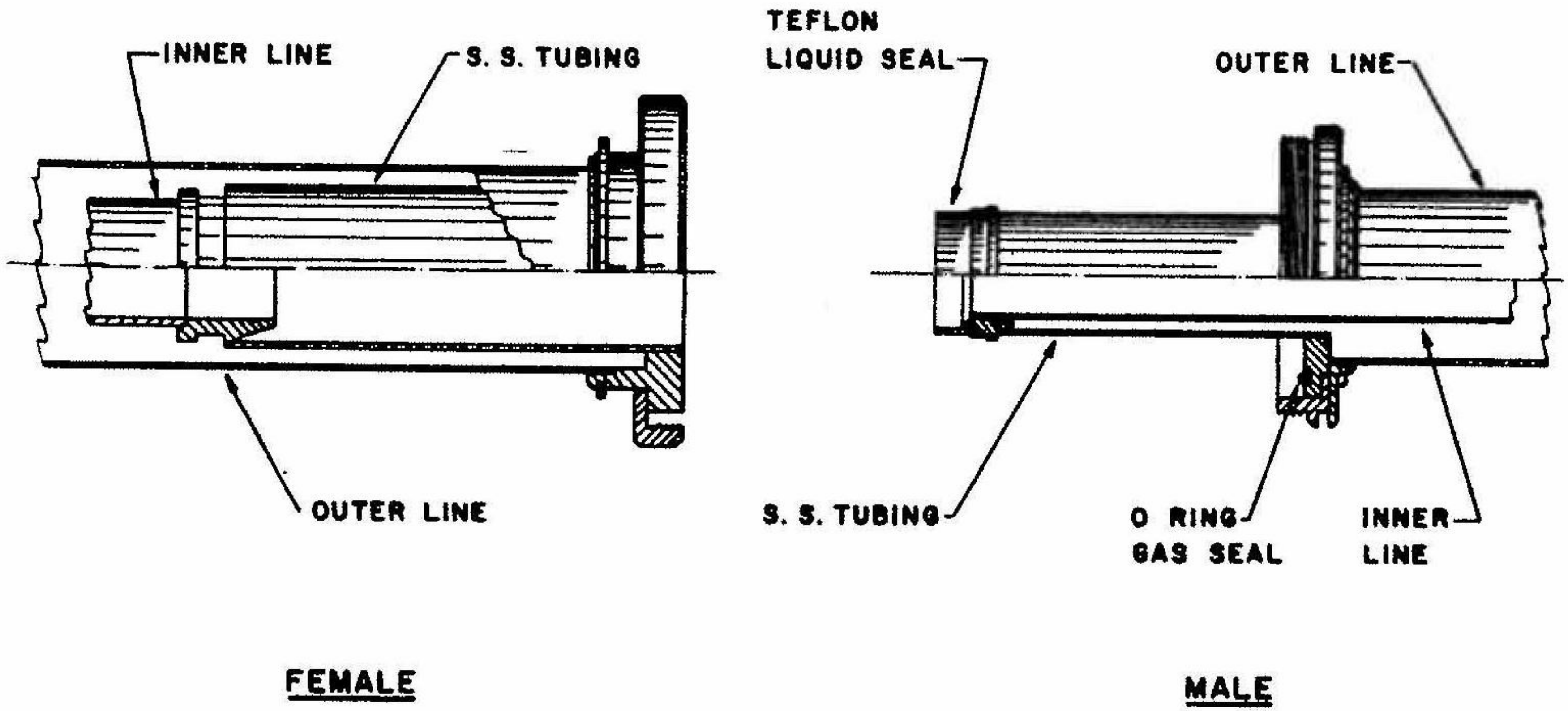
PBA Series Bayonet from PHPK Technologies



Note:
No liquid seal
Very tight tolerances between
male & female sides to minimize convection
Long, thin walls connect 300 K and 4.2 K

Air Force Style Hydrogen Bayonet

from "Cryogenic Equipment" – D. Daney Handbook of Cryogenic Engineering



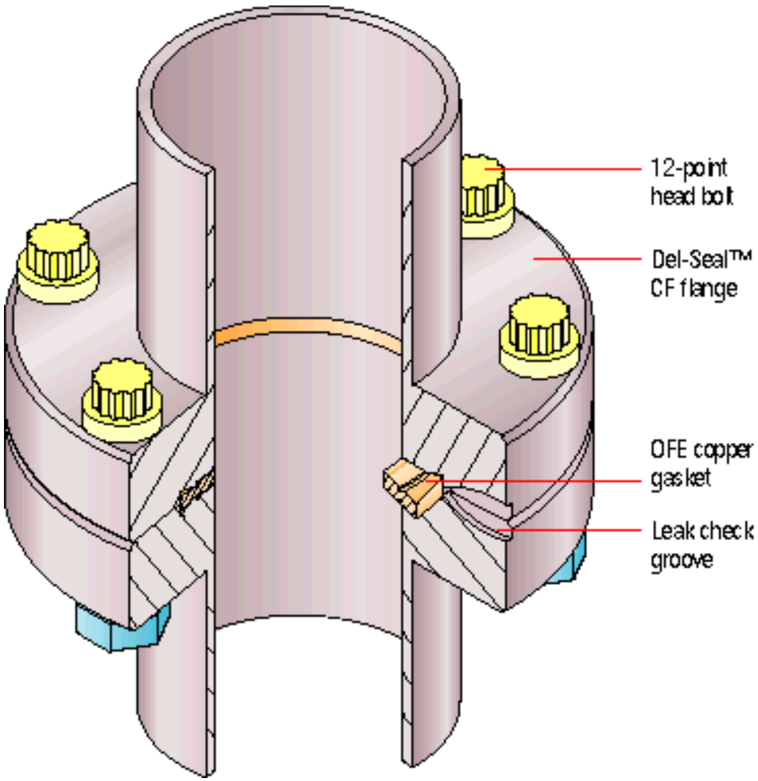
FNAL/SMTF Bayonet Can

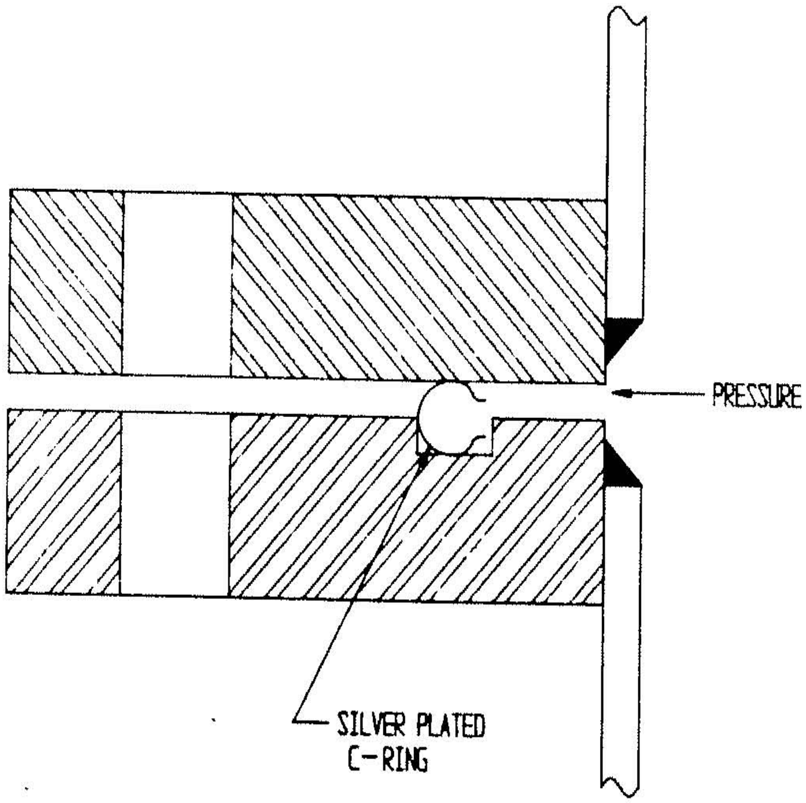
SNS Refrigeration Plant showing U-tubes

Flange Connections

- How else do we connect pipes at cryogenic temperatures?
  - Welding is almost always the most reliable approach but sometimes a demountable joint is required.
- There are a number of demountable flange options
  - Anything involving a polymer or rubber O-ring will clearly not work at cryogenic temperatures
  - Sealing options include
    - » Flanges using a soft metal gasket (typically copper) such as Conflat flanges
    - » Flanges using a metal "c" ring
    - » Flanges using an indium o-ring – best used in test scenarios and typically home-made
  - With proper design and installation all of these approaches can provide leak tight joints down even at superfluid helium temperatures (< 2.2 K)
- Note that vacuum and liquid leaks are a major source of problems in cryogenics. Carefully thought out and reliable connections are a key to success

Examples of Flanged Connections for Cryogenic Use (both are commercially available)

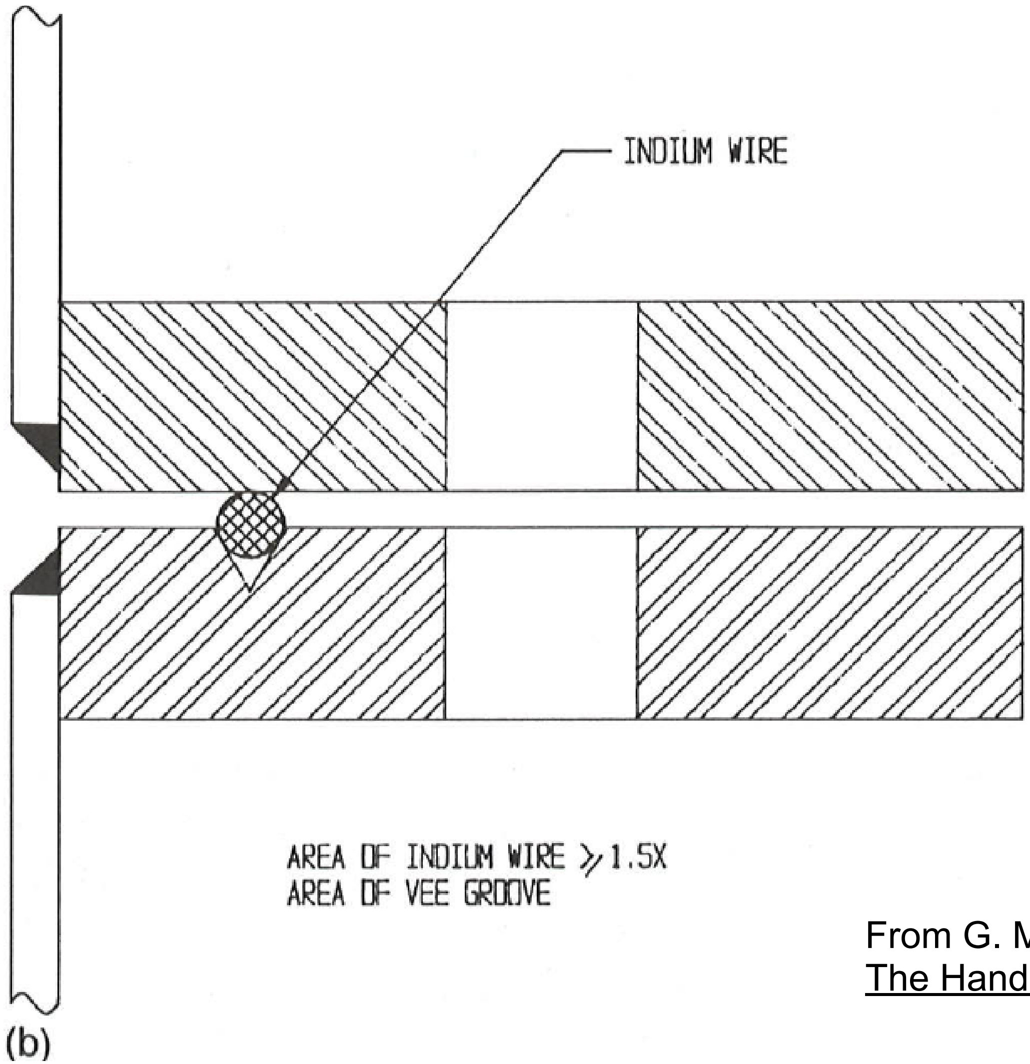




ConFlat Style
Soft Metal Gasket

C Ring Style

Example of Indium O-Ring Seal



From G. McIntosh in
The Handbook of Cryogenic Engineering

Use of Invar Washers

- If upon cool down the flange material shrinks more than the bolt material then the seal may open up and leak
- One way to prevent this is to use invar washers so that the seal actually tightens during cool down
- The goal here is to size the components such that the bolt shrinks more than the combination of the 2 flanges and the invar washer

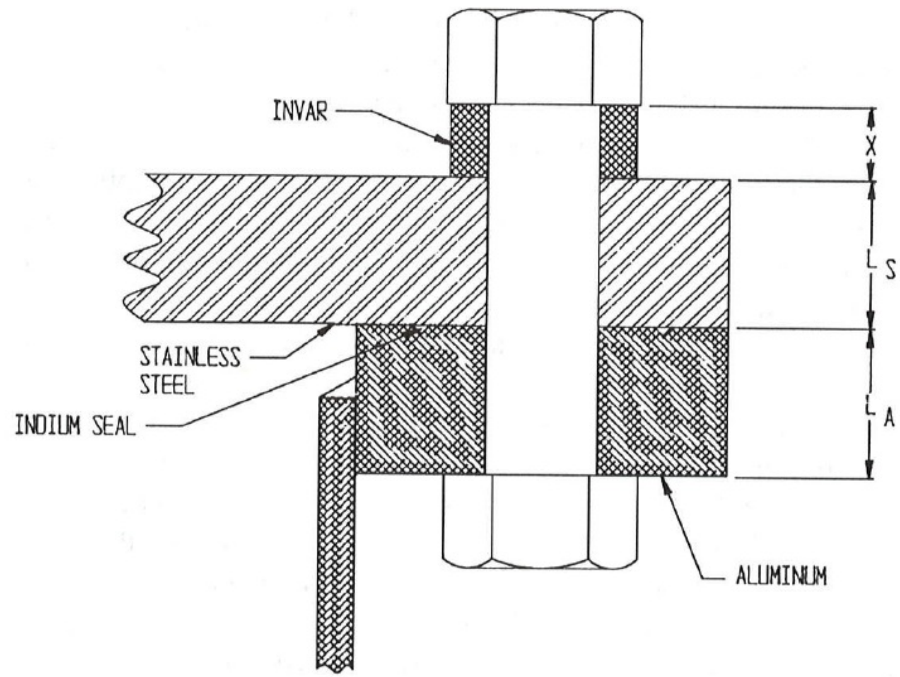
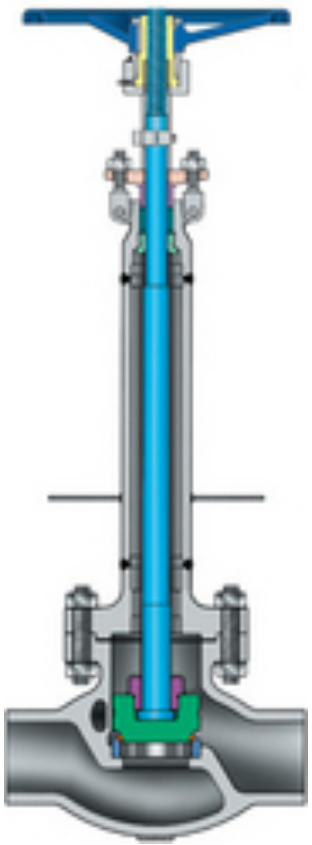


Figure 5-1 Flange joint with Invar washer.

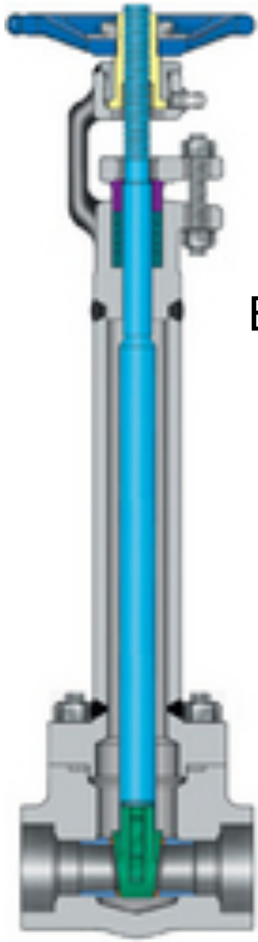
Valves

- Valves are an important part of cryogenic systems
- Valves direct flows and control both flow rates and pressure drops
- Cryogenic valves have to operate at cryogenic temperatures and minimize the heat leak from room temperature
- Except in very specialized cases, cryogenic valves have room temperature actuators
- Valves can be manually operated or more commonly operated via a control system. The actuators for remote operation are typically electro pneumatic – a current or voltage signal from the control system regulates the pressure on the pneumatic drive that controls the valve position.
- A wide range of cryogenic valves is available in industry

Basic Valve Types
(All can be implemented in cryogenic systems with proper design and materials)

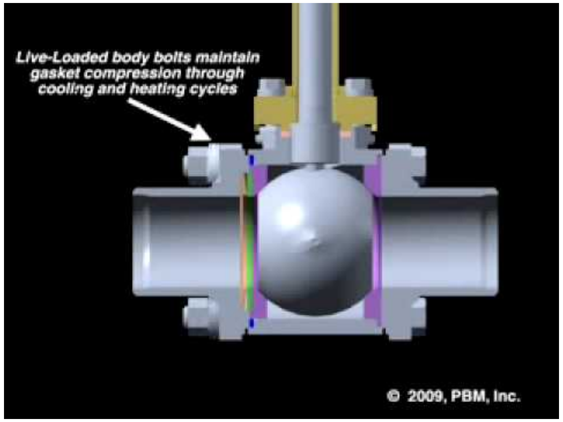


Globe



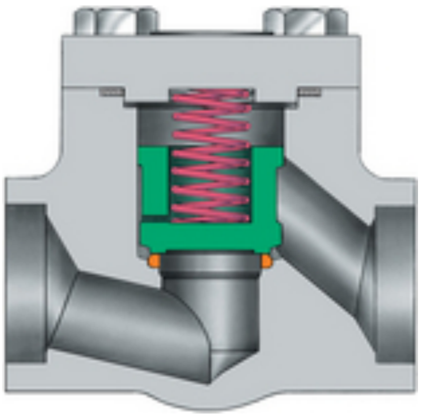
Gate

Ball



Butterfly

Relief



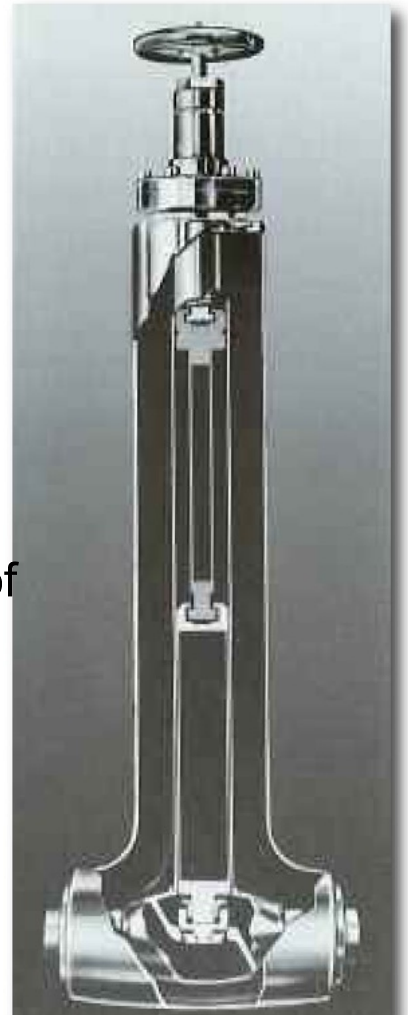
Check

Examples of Cryogenic Valves

CVI
Model 2060

Contains
vacuum jacket
Heat Leak reduced
via thin walled tubes

1 inch valve has a
measured heat leak of
1.3 W to 4.2 K



JT Valve

Cryocomp

½ inch IPS

Designed to be installed inside cryostats

Heat Leak to 4.2 K is ~ 1 W

Sizing of Valves

- Valves are typically sized using the parameter C_v
  - This parameter is defined as the number of Gal/min of water that passes through the valve with a pressure drop of 1 psi
  - This can be related to properties we care about in cryogenics by
  - Be sure to use appropriate properties
  - Note $^oR = (9/5)K$

From Acme Cryogenics Catalog

Liquid Flow

$$C_v = \frac{Q_L\sqrt{G}}{\sqrt{\triangle P}} = \frac{7.2W_L}{\sqrt{G\triangle P}}$$

where:

C_v = Valve Flow Coefficient

^{3}P = Pressure Drop (psi)

Q_L = Liquid Flow Rate (gpm)

G = Specific Gravity = $\frac{\text{density of subject fluid}}{\text{density of water}}$

W_L = Liquid Flow Rate (lbs/sec)

Gaseous Flow

$$C_v = \left|\frac{\sqrt{T}}{22.8}\right| \frac{Q_g\sqrt{G}}{61\sqrt{P_1\triangle P}} = \frac{730W_g}{\sqrt{GP_2\triangle P}}\left|\frac{\sqrt{T}}{22.8}\right|$$

where:

C_v = Valve Flow Coefficient

$\triangle P$ = Pressure Drop (psi)

Q_g = Gaseous Flow Rate (scfh)

G = Specific Gravity = $\frac{\text{density of subject gas at stp}}{\text{density of air}}$

W_g = Gaseous Flow Rate (lbs/sec)

P_1 = Absolute Upstream Pressure (psia)

P_2 = Downstream Absolute Pressure (psia)

T = Absolute Temperature (^oR)

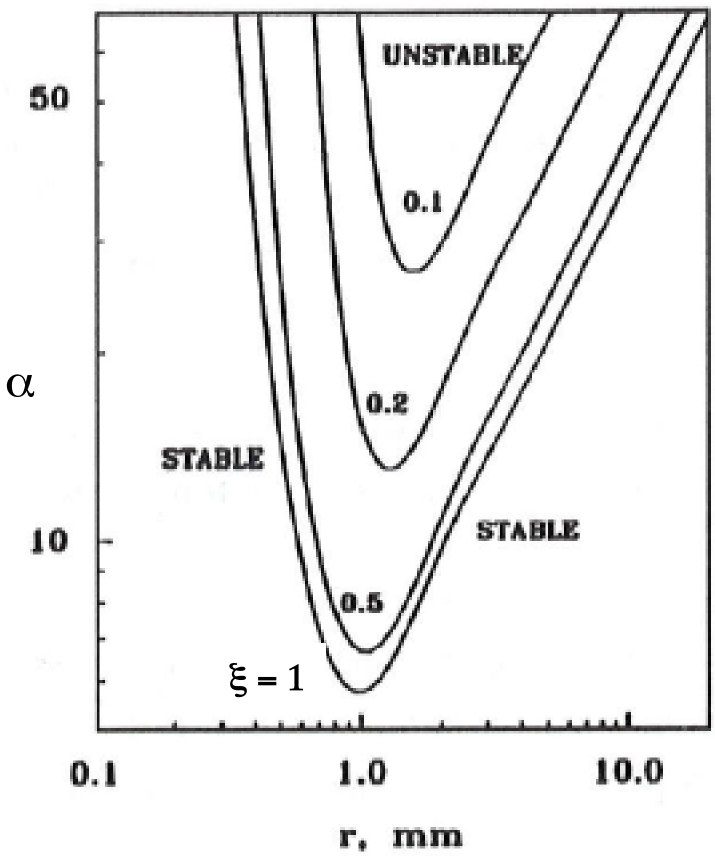
Note: When the pressure drop ($\triangle P$) is equal to or greater than $1/2$ the absolute upstream pressure (P_1), substitute

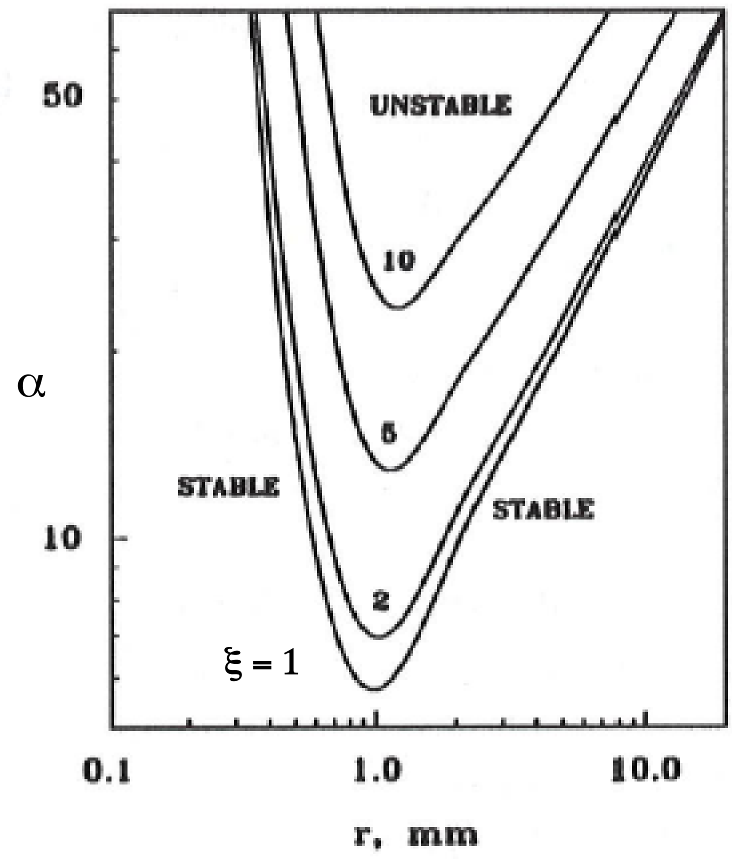
$$\left|\frac{P_1}{2}\right| \text{ for } \sqrt{P_1\triangle P}$$

Thermal Acoustic Oscillations (TAOs)

- Occurs in a tube that connects room temperature and cryogenic temperatures and is sealed at the room temperature end
- The thermal gradient establishes standing pressure oscillations in the fluid in the tube. (Recall thermal acoustic oscillators in Lecture 11)
- These oscillations can cause very high pressure spikes as well significant heating at the low temperature end due to friction.
- This can cause significant problems in cryogenic systems
- Such scenarios should be avoided but the enabling geometry is fairly common in cryogenic systems
  - Valved off lines
  - Pressure taps
  - Instrumentation
- There have been studies to determine stable (non-oscillating geometries)

Stability Curves for TAOs in He





Y. Gu
PhD Thesis
University of Colorado 1993

Using the Stability Curves

$$\alpha = \frac{T_H}{T_c}$$

$$\xi = \frac{L_H}{L_C}$$

Where the division between L_H and L_C is the point in the tube where $T = (T_H + T_C)/2$

These curves are for a 1 meter long tube. To use them with other lengths use the Adjusted radius:

$$r' = \frac{r}{\sqrt{L}}$$

Stability on the left hand side of the plots is due to viscous damping and stability on the right hand side of the plots is due to inertial damping

Other Approaches to Removing TAOs

- Add volume to the warm end
- Install a check valve between the warm and cold end (near boundary between the two) – this converts the problem to a closed cold tube with no TAOs
- Heat sink the closed end (thus changing T_H/T_C)
- Allow flow through the warm end