Hydrogen Products

Choosing the Right Components for H_2

Hydrogen Applications

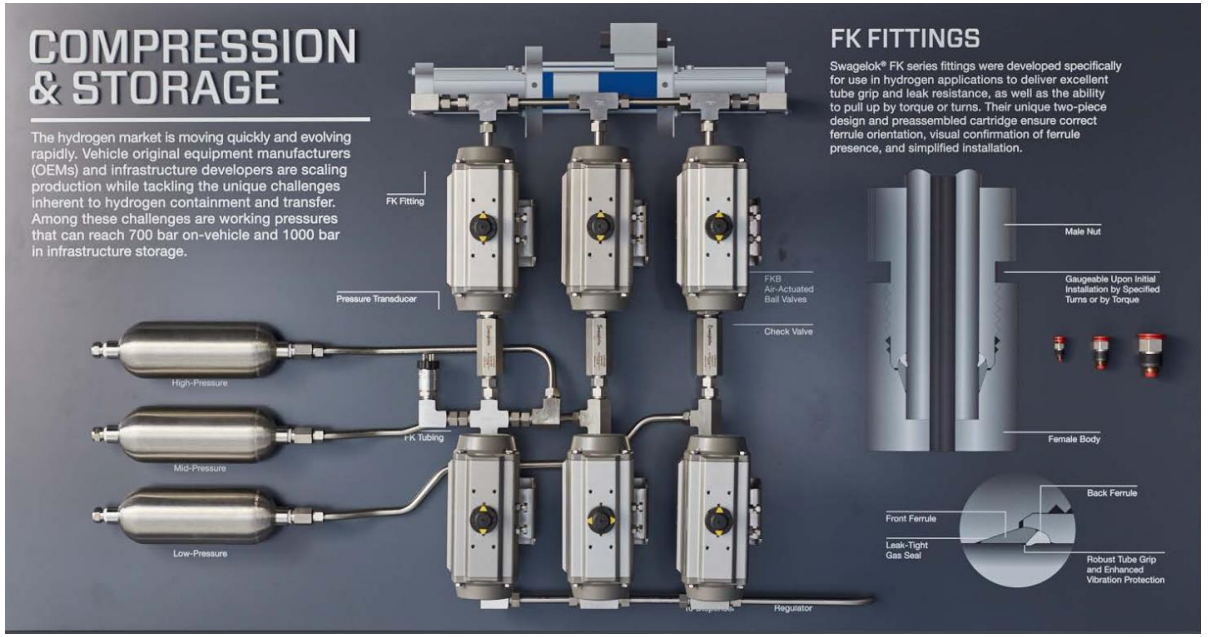
Speakers

Chuck Hayes
Principal Applications Engineer, Clean Energy
Swagelok

Chuck Hayes is a 30-year veteran of Swagelok Company, a world leader in the development of fluid system products, assemblies, and services. He has spent the last 25 years developing a wide range of fluid system products and the past 20 years focused exclusively on fitting technology for alternative fuel applications. Chuck currently holds 7 patents in the US and numerous patents internationally.

He is an active member of CSA (Canadian Standards Association Group) committees for both CNG and Hydrogen and has recently been the chair of HGV (Hydrogen Gas Vehicles) 4.10 for fittings. Chuck also sits on ISO-TC97 (Technical Committee) and participates in international working groups. During his time as Principal Applications Engineer for the transportation market, Chuck has supported numerous on-vehicle platform development projects globally.

Today, he concentrates most of his time on the development of hydrogen mobility solutions for both refueling infrastructure and on-vehicle applications.



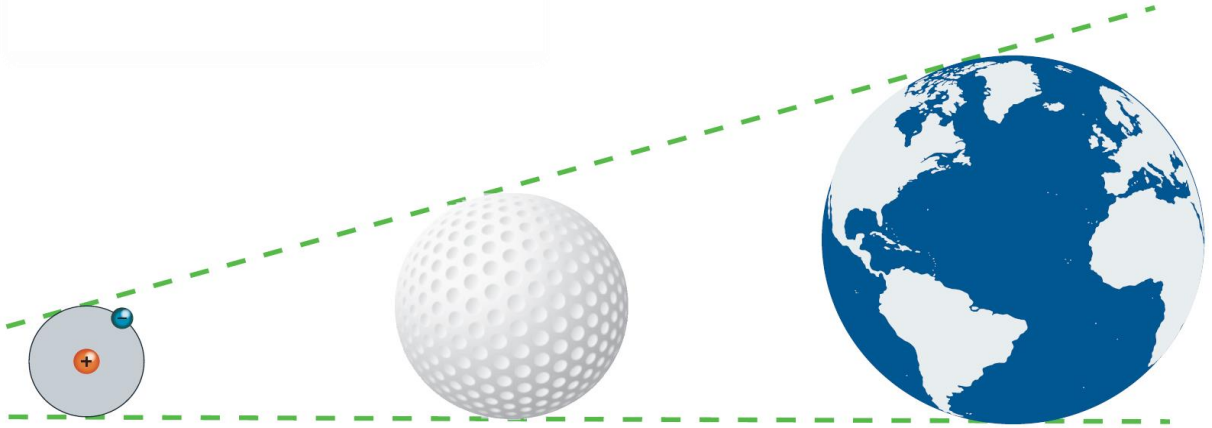
The unique nature of H2

Operating conditions for H_2 fuel system components are inherently challenging

- Pressures: To achieve desired density, H_2 must be stored in on-vehicle tanks at 250 – 900 bar
- Stress and vibration: Systems must be able to withstand fast speeds, bumpy roads, and inclement weather conditions
- Safety: Refueling stations must be safely operable by the average consumer
- Maintenance: Ability to easily remake leak-free joints during servicing

Hydrogen embrittlement

- H2 molecules can diffuse into stainless steel
- Pressure and time can produce fissures
- 316/316L materials are critical



Hydrogen Safety

https://h2tools.org

Leak-tight Integrity = Quality and Safety

Hydrogen fluid systems components can leak for a variety of reasons

- Leaks in sealing areas
- Permeation leaks
- However, good design can mitigate the effects of leaks
- Unfortunately, not all solutions are created equal
- Let’s start here and build up from the basics

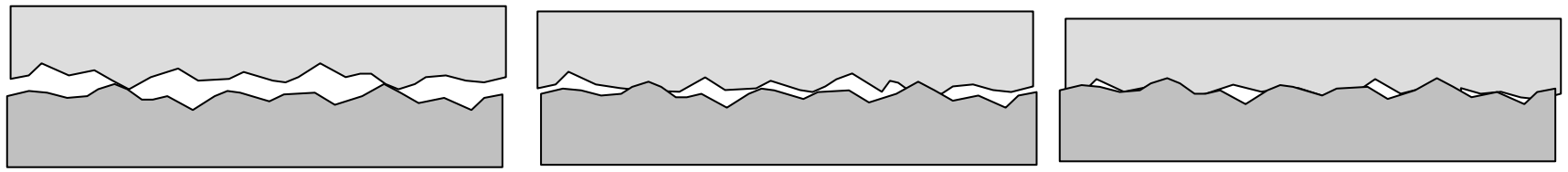
Creating a Seal

Objective: Eliminate **continuous pore structure** between mating surfaces

- **All machined surfaces have a degree of roughness,**
- **Peaks and valleys can link to make leak paths**

All-metal fittings: Employ plastic deformation of metal surfaces to create the seal (Swagelok fitting)

Valves: Typically employ plastic / elastic / viscoelastic deformation of plastics, elastomers, or grease materials to create a seal



2-dimensional representation of rough surfaces coming together to form a seal.

Permeation vs Leakage

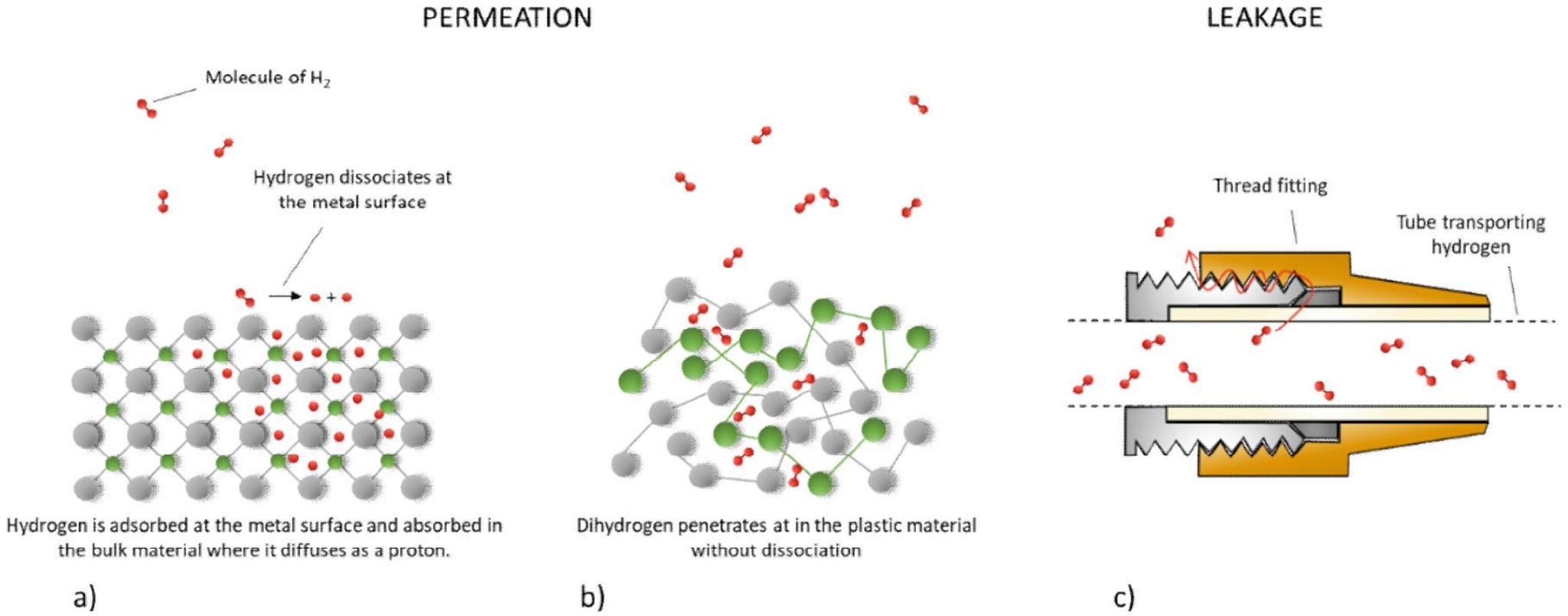
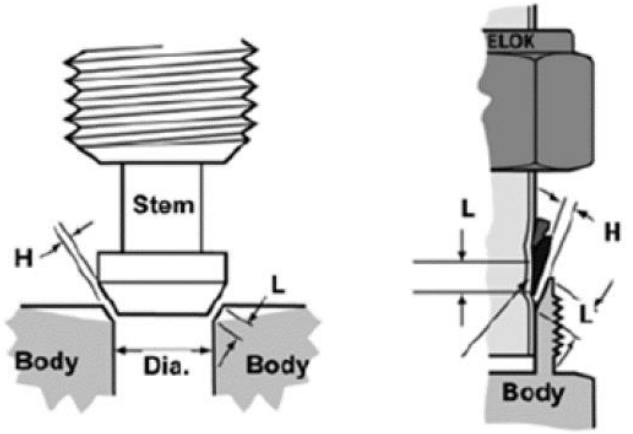


Figure 21 : Schematic representation of permeation in a) a metallic and b) a polymer material and c) leakage through a fitting in hydrogen gas environment.

Leak Paths



Assuming that the parameters are known, the flow rate in a system can be estimated using the following formula (*Swagelok Tube Fitters Manual*, n.d.):

$$Q = \frac{\Delta P \times H^3 \times W}{\mu \times L}$$

Equation 3

Where, Q is the flow rate of the leak [$m^3.s^{-1}$], ΔP is the pressure drop, W is the circumference of the seal, μ the absolute, or dynamic viscosity [$kg.m^{-1}s^{-1}$], H the height of the gap, and L the length of the leakage path, Figure 22. The dynamic viscosity is different from the cinematic viscosity which is the ratio of the dynamic viscosity of the fluid to its density [$m^2.s^{-1}$].

Current Fitting Technology: Cone and Thread

Cone and Thread Fitting—IPT Series

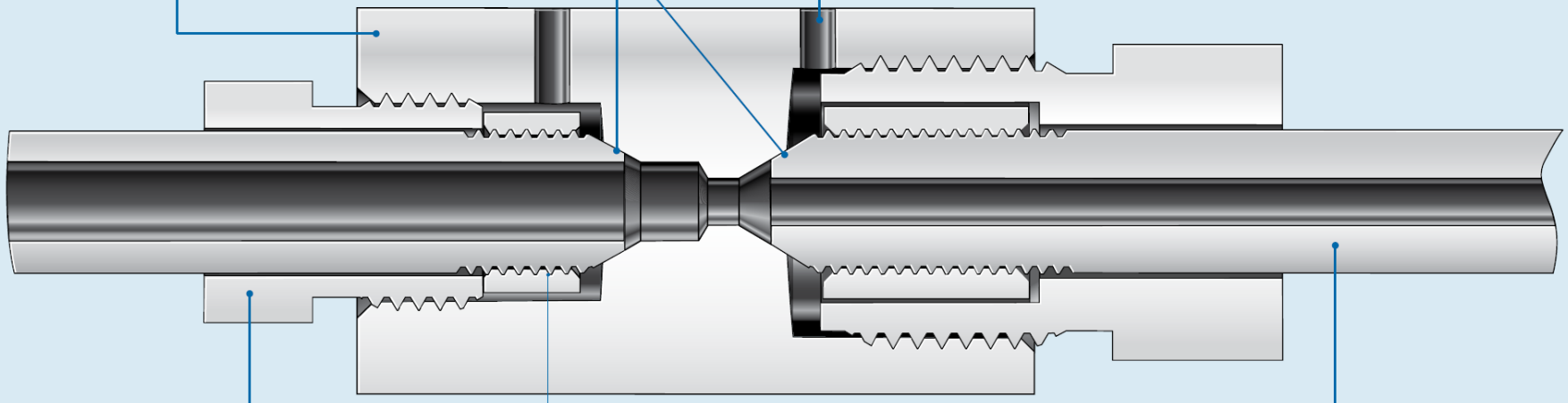
Medium-pressure cone and thread end connection shown on left side of fitting

High-pressure cone and thread end connection shown on right side of fitting

Fitting body

Primary seal surface

Weep hole enables leak detection and verification of a proper installation.



Gland creates a load on the collar to ensure a seal on the tubing and body angle area.

Collar threads onto the cone and thread tubing with left-hand threads to prevent accidental disassembly of collar during installation.

Cone and thread tubing is required for cone and thread fitting installation. High-pressure tubing has a thicker wall than medium-pressure tubing.

New Learnings on Coned Seal Technology

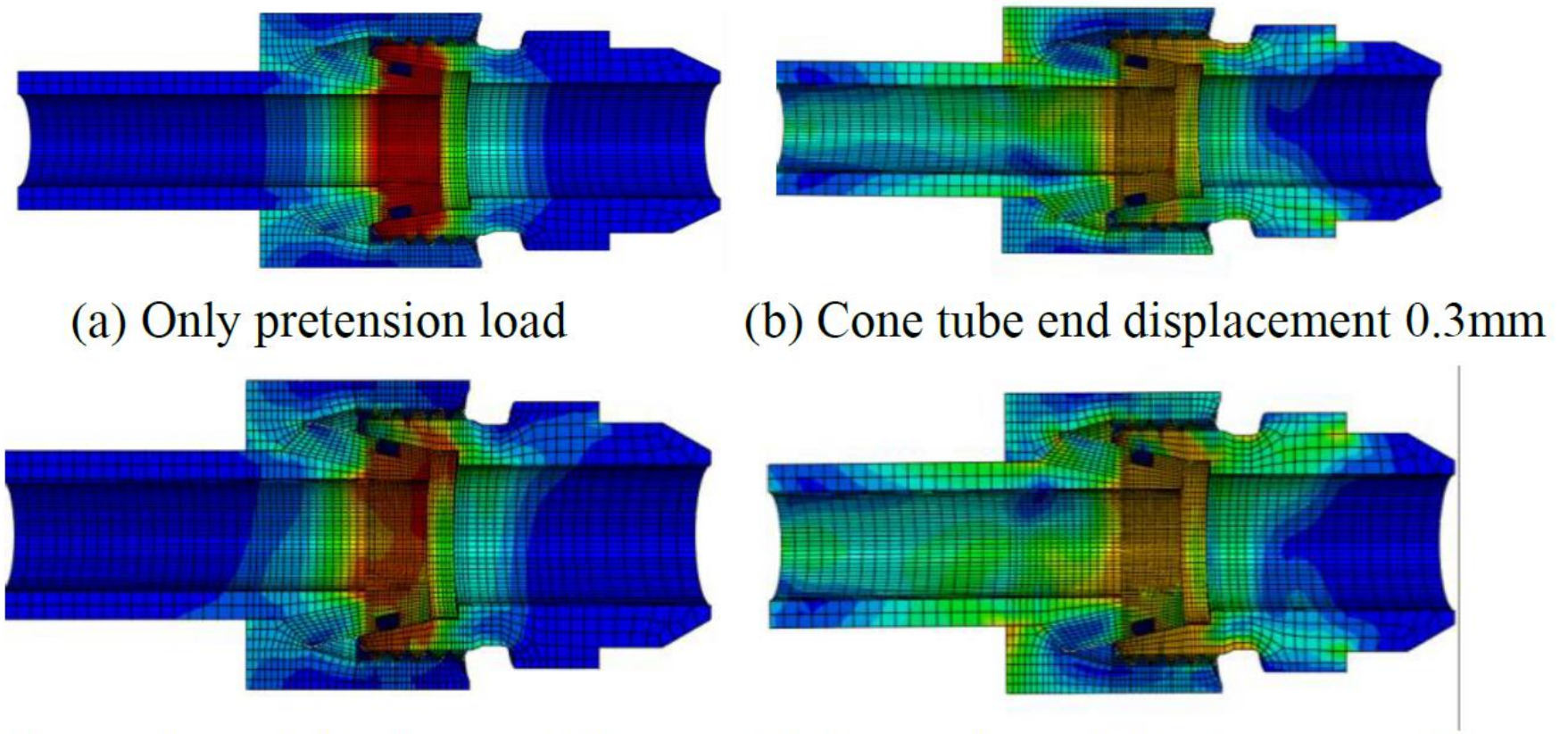


Fig.2. Mises stress distribution of cone sealing structure

Ke Bao *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **322** 072068

Considerations with Cone and Thread

No international standard for C&T Fittings

Companies create their own standards

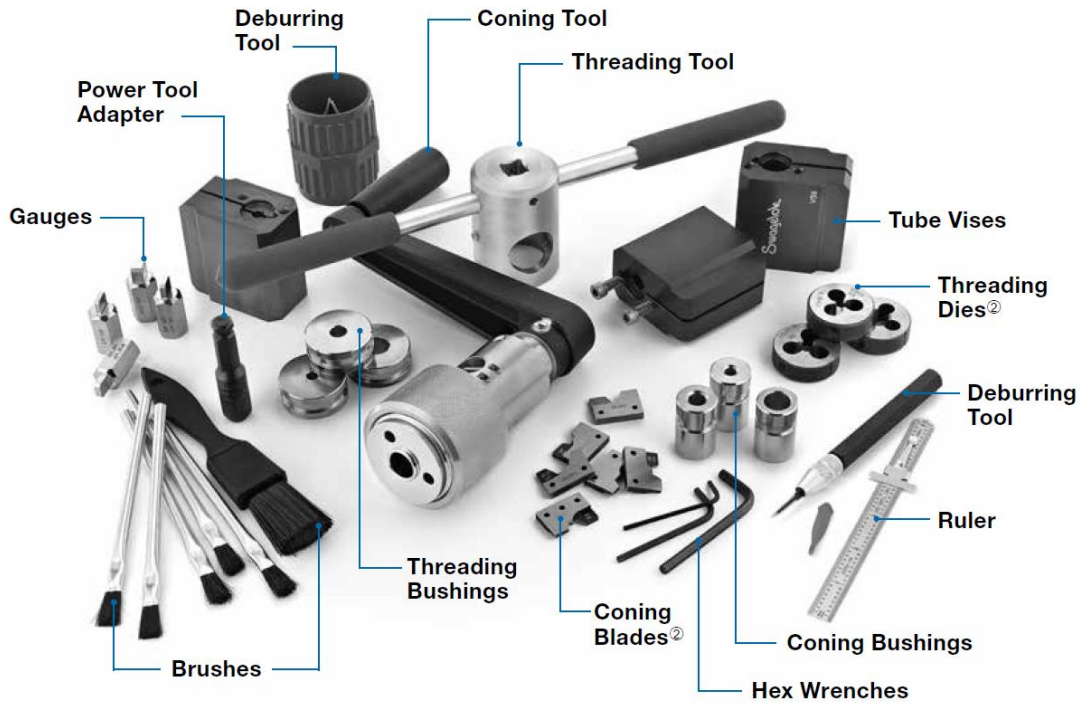
- Cones and bodies vary from 57° to 63°
- Dissimilar angles can lead to single line of contact with cone and body

Coning often performed in field with hand tools or benchtop tools

Consistency of the cone can vary significantly based on operator skill

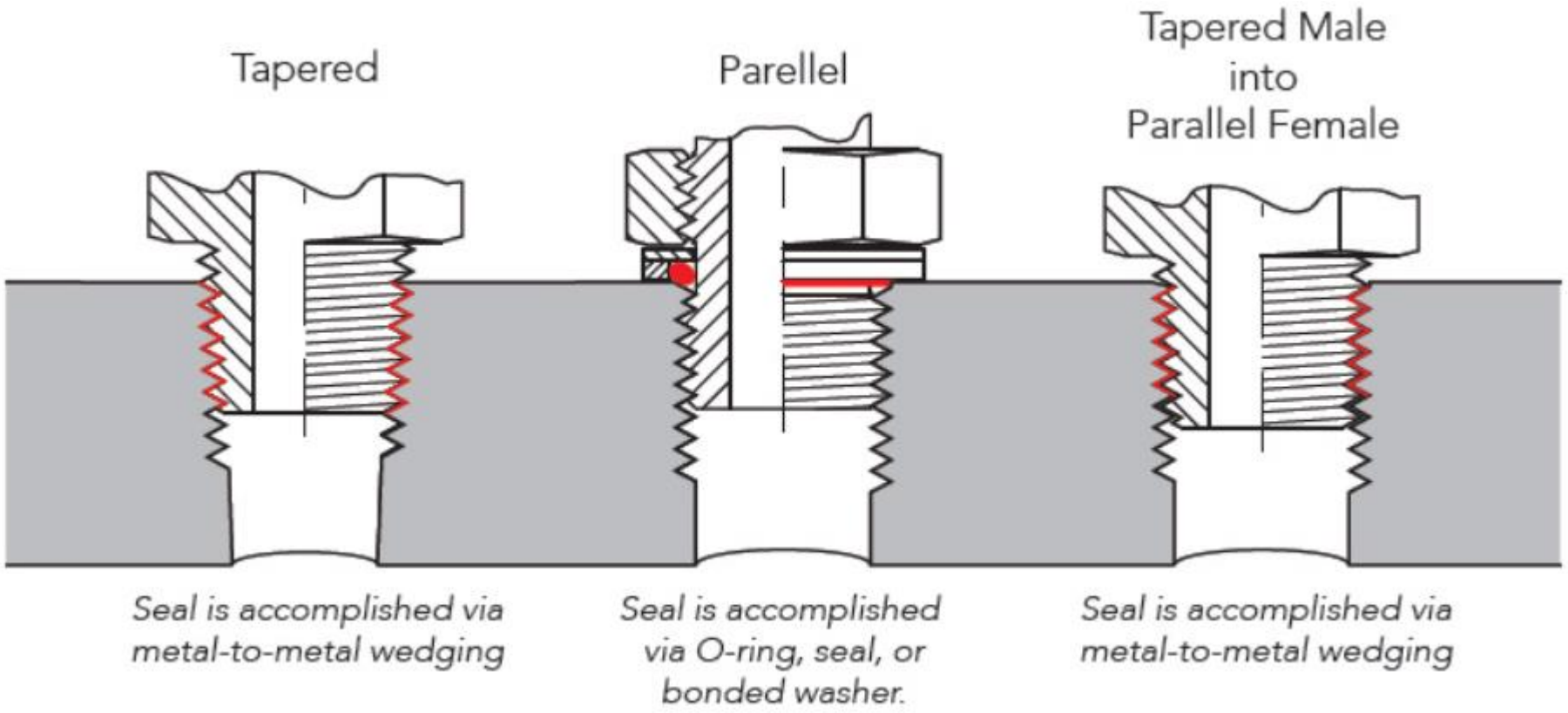
Very susceptible to vibration failure

Require grease to create seal



Kit for Coning and Threading

Current Fitting Technology: Threaded Joints



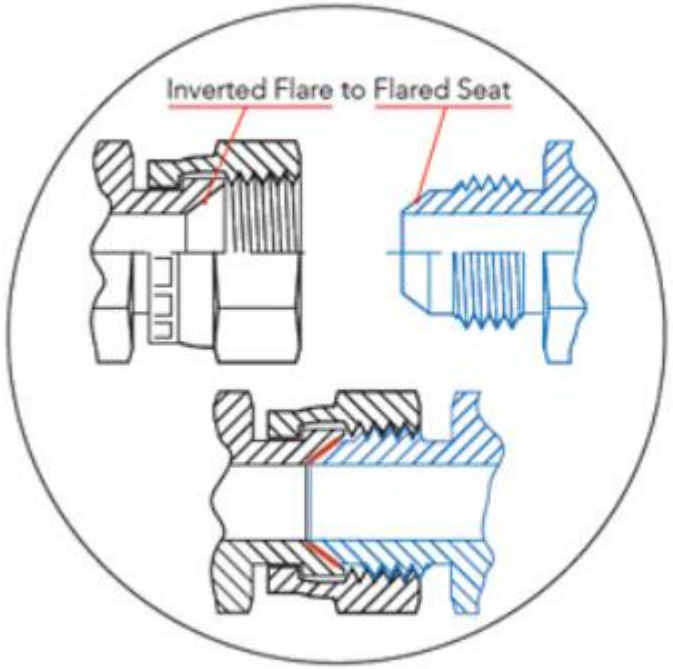
Creates a spiral leak path

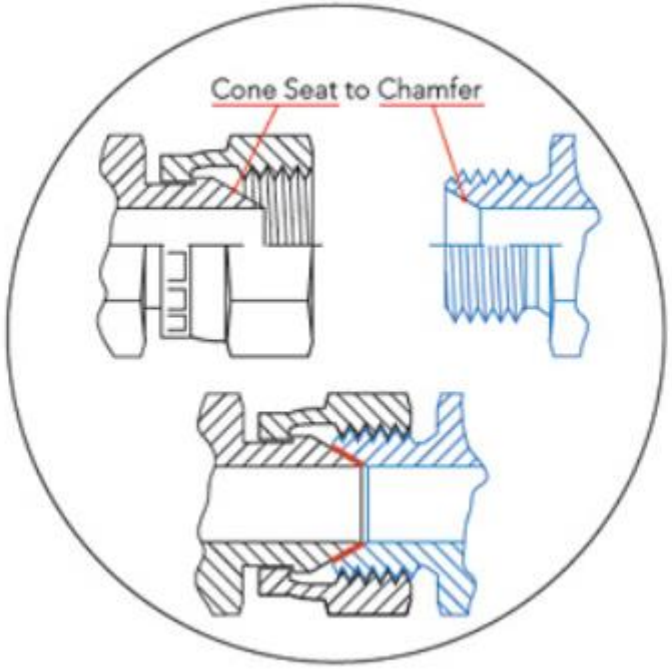
Relies on commodity seals

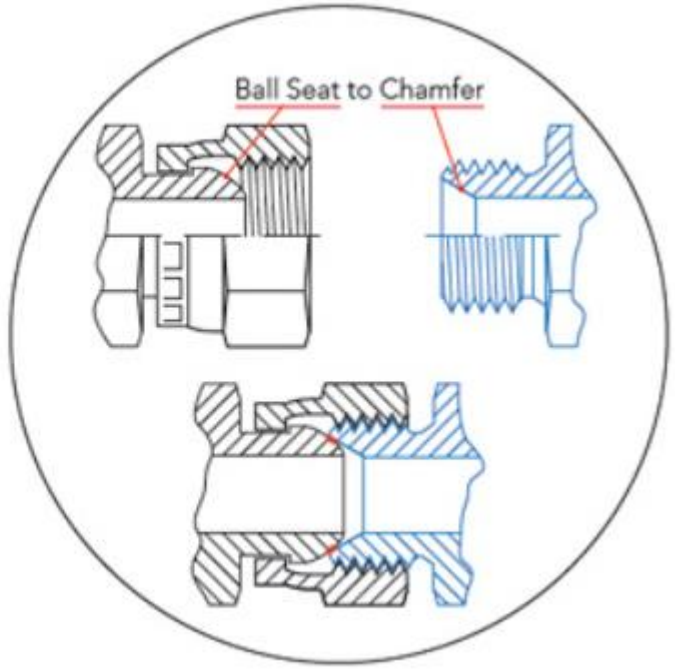
Creates a spiral leak path

https://www.adaptall.com/info-tutorials/sealing-methods.php

Current Fitting Technology: Flare Style Fittings





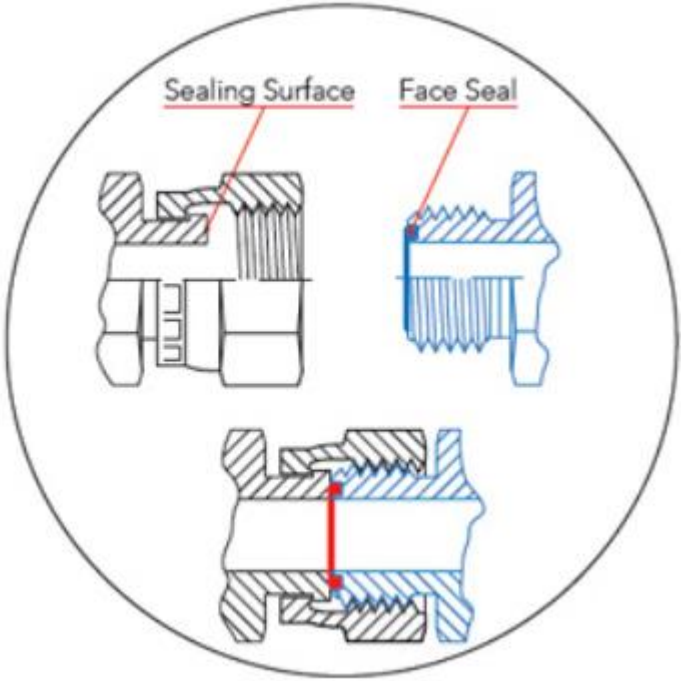


Angle on angle seals cannot ensure long seal areas, may coin

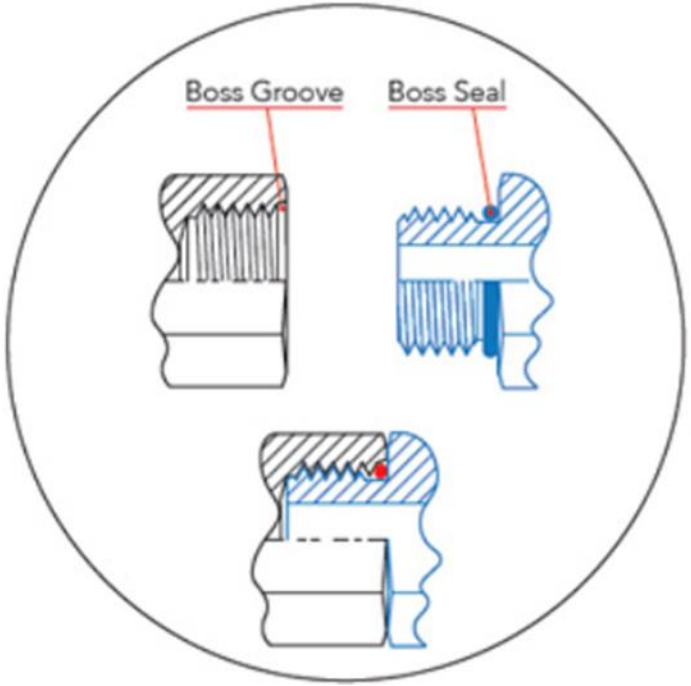
Ball on chamfer creates a single line seal

https://www.adaptall.com/info-tutorials/sealing-methods.php

Current Fitting Technology: O-ring Sealing Fittings



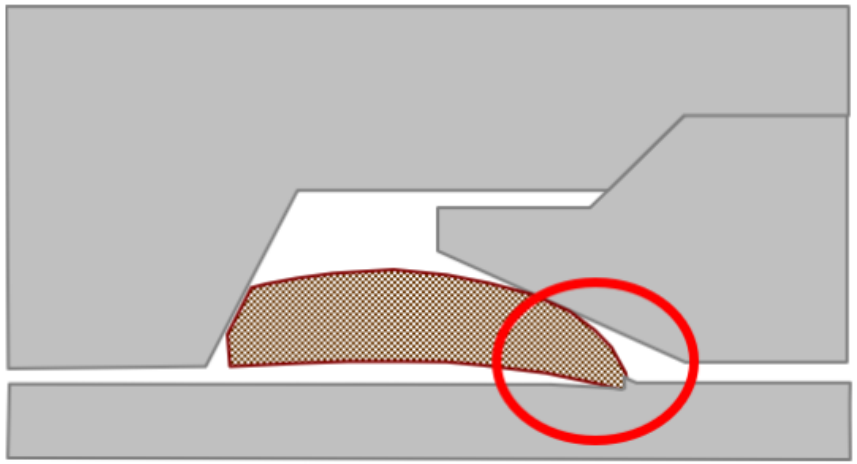
ORFS seals rely on internal system pressure to seal, meaning the seal can move on every pressure cycle



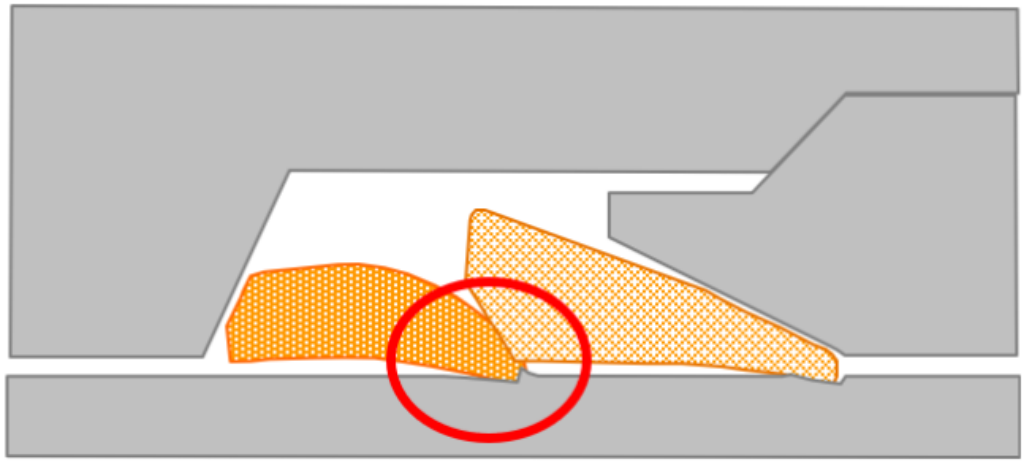
SAE J1926 can work but needs correct O-ring & appropriate torque; in 700 bar systems, aluminum bodies are beyond yield when torqued properly

https://www.adaptall.com/info-tutorials/sealing-methods.php

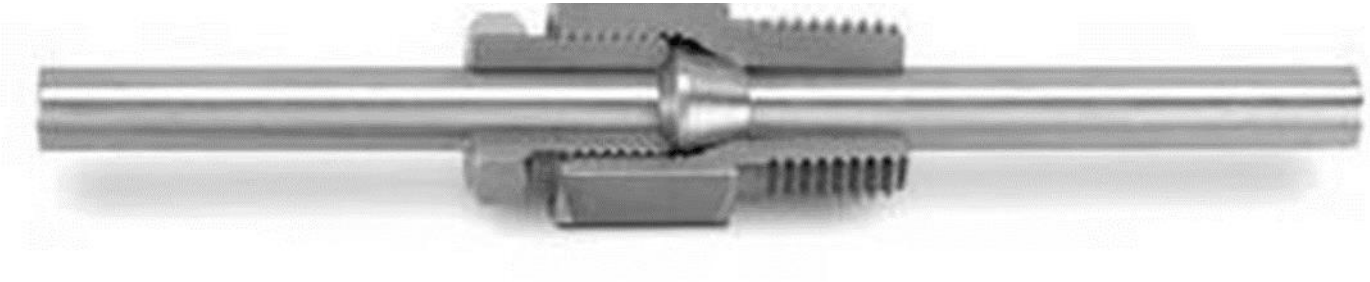
Current Fitting Technology: Single Ferrule Bite Style



Single Ferrule Bite-Type Fitting



Twin Ferrule Bite-Type Fitting



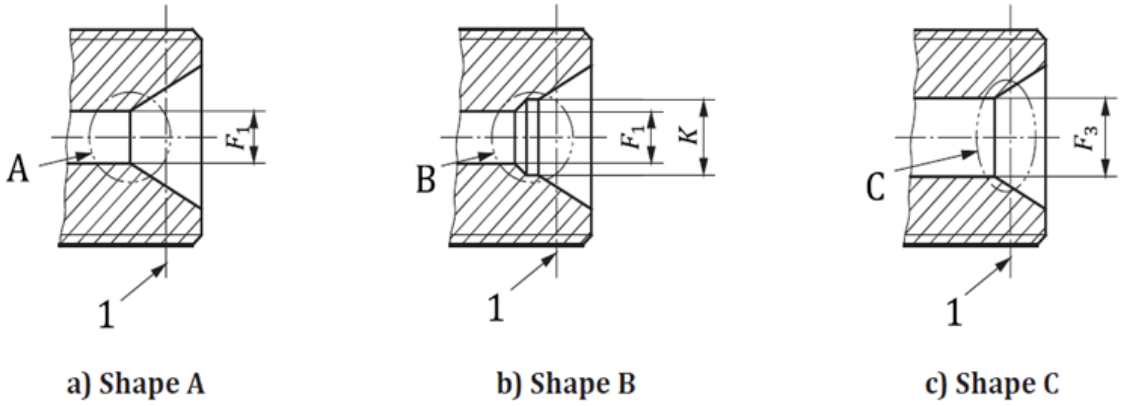
Single Ferrule Fittings: Either Bite and introduce a stress riser or single line of contact of limited L and no elasticity

https://www.adaptall.com/info-tutorials/sealing-methods.php

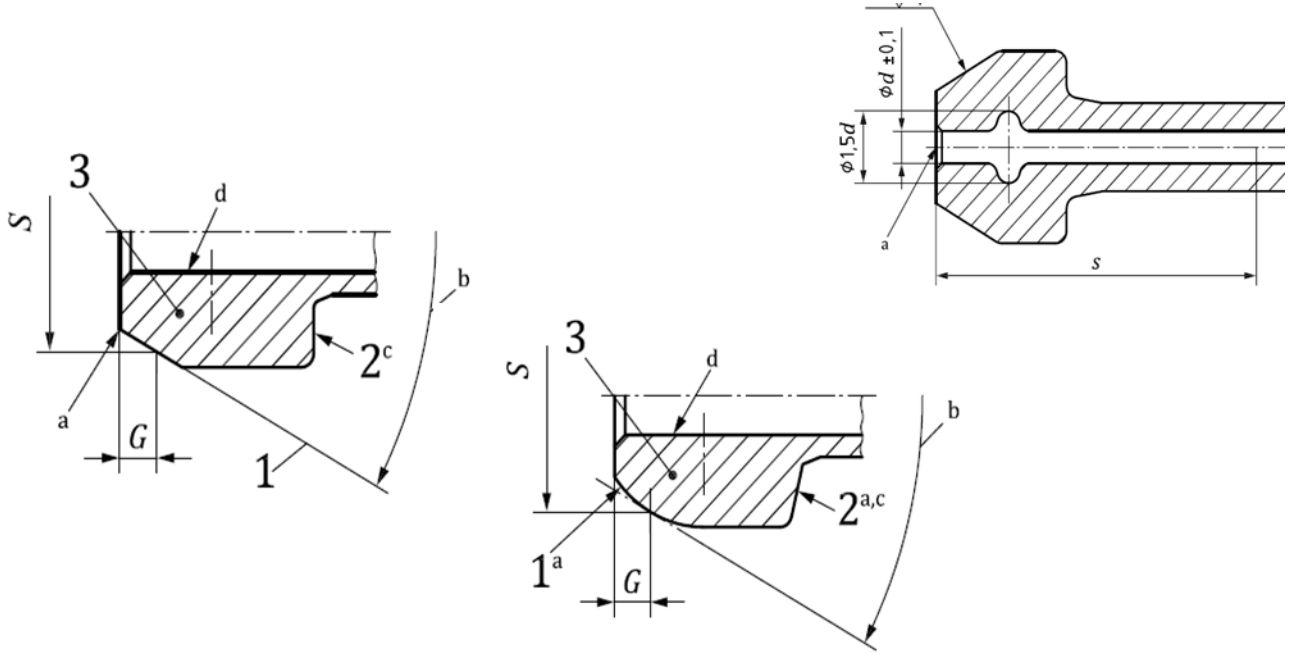
Current Fitting Technology: Diesel Style Fittings (Manipulated End)

ISO 13296 describes a manner for manipulating the end of tubing to create an upset near the end of the tube

This fitting design has been used for high-pressure diesel fuel rails up to 36kpsi



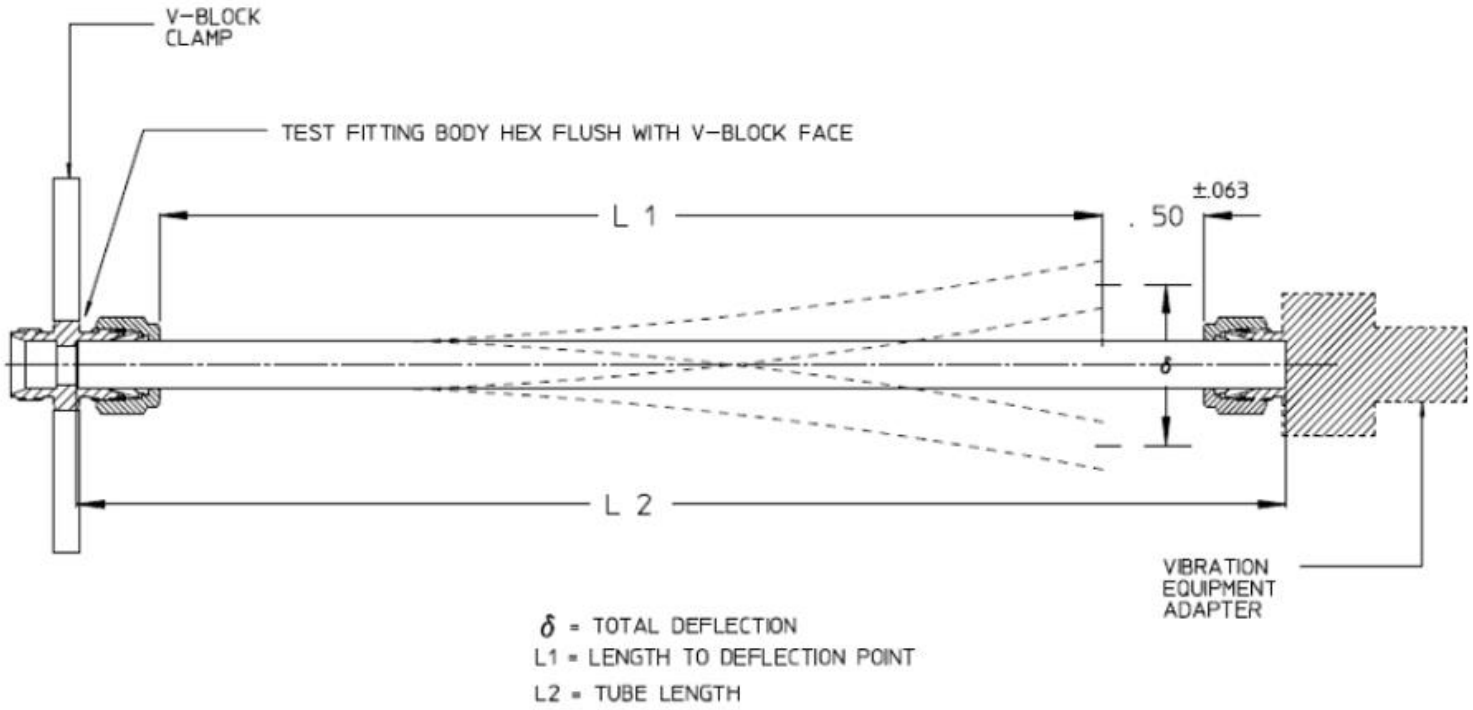
Body designs

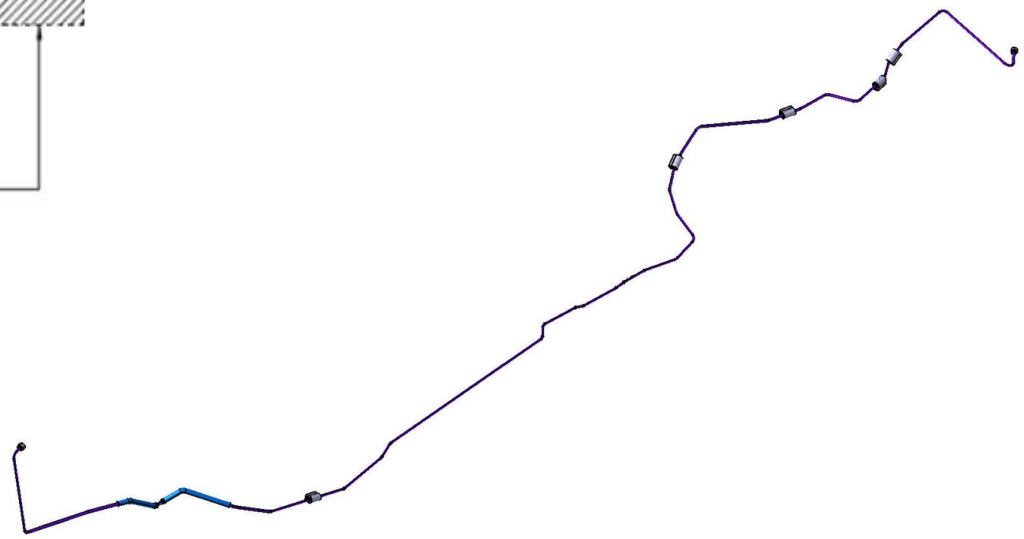


Manipulated tube ends

Vibration: Rotational Flexure Stress Test

Rotary flexure fatigue testing adds a realistic load that comes in transportation environments





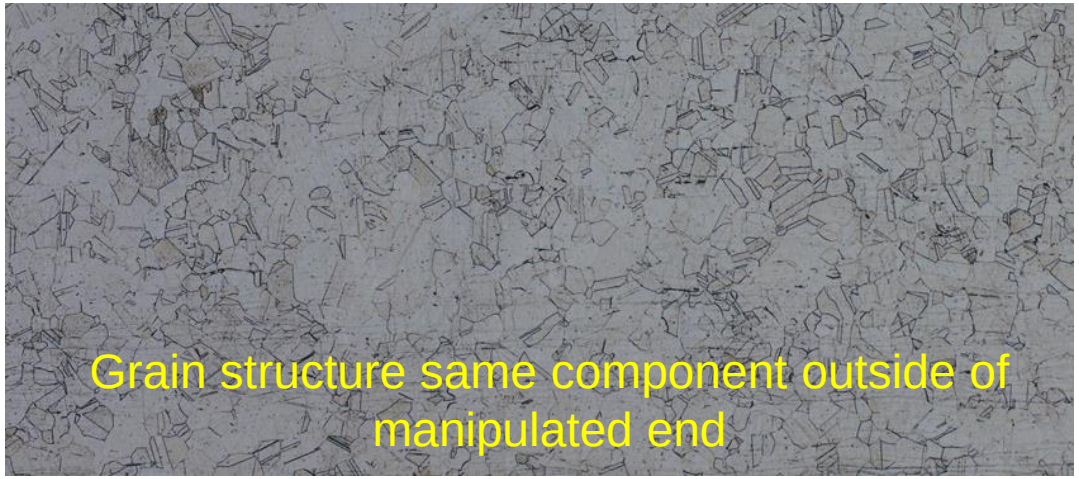
Micro-structure After Manipulation

Dark-etched surfaces indicate extremely hard material

Cold working of material causes significant changes to grain structure

Inner structure of grains shows complete destruction of grains due to cold working far beyond plastic limit

Cracks are very evident on inner structure



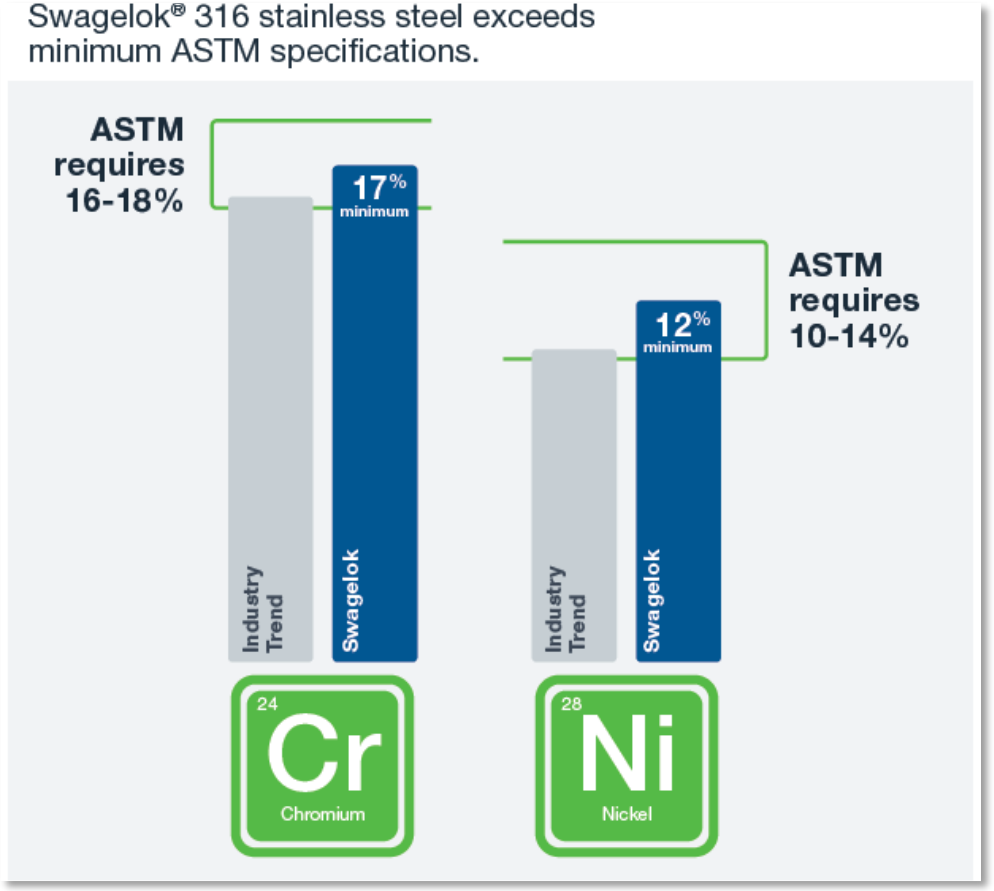
Performance Characteristics: Material Integrity

316/316L stainless steel alloys:

- Nickel (stabilizes crystal structure of steel)
- Chromium (corrosion-resistance)
- Molybdenum (corrosion-resistance)

Combatting H_2 embrittlement and corrosion

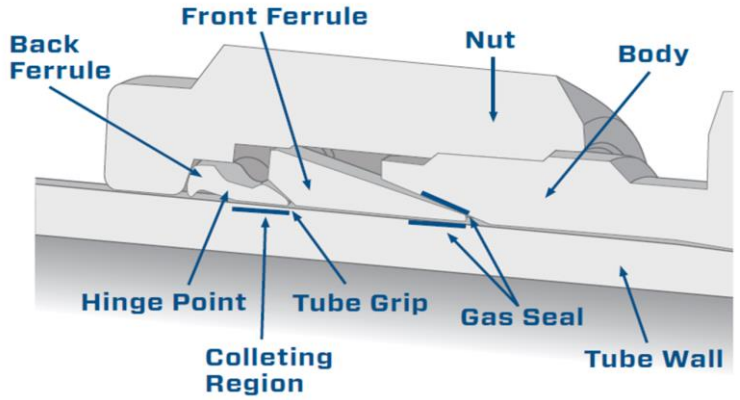
- Higher concentrations of Ni and Cr provide greater ductility
- ASTM minimum requirements for 316 stainless
  - >10% Ni
  - >16% Cr



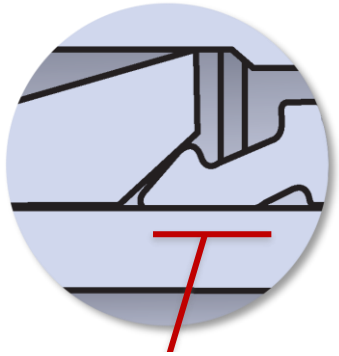
Swagelok Tube Fittings

The Solution to Small Molecule Gas

The Swagelok Tube Fitting Advantage



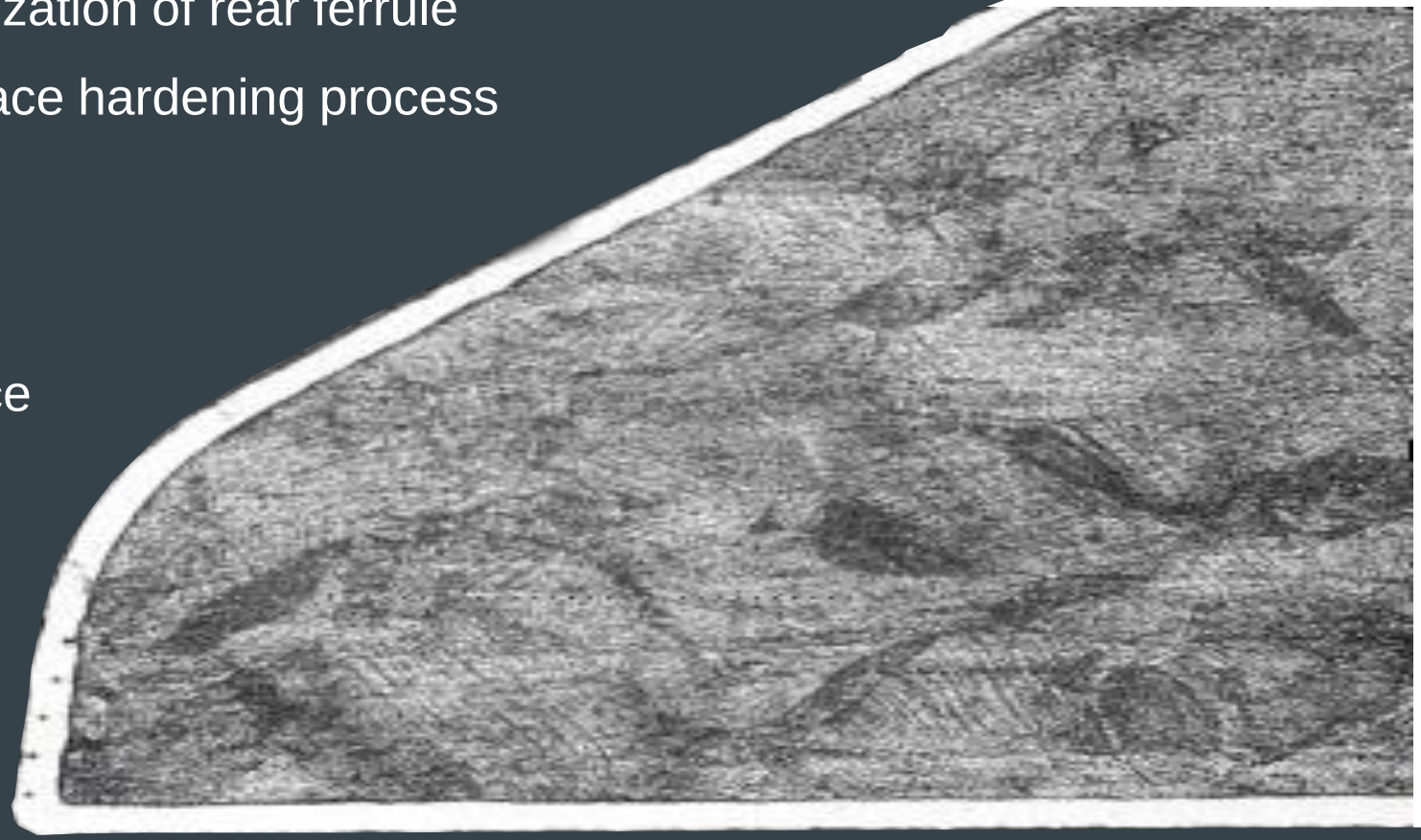
- Swagelok tube fittings have a grip-type design that uses a unique “hinging and colleting” action to achieve optimal performance and vibration resistance
- Patented SAT 12-hardened surface delivers extraordinary hardness while retaining ductility and corrosion resistance
- Gas seal is created by a burnishing action of the front ferrule along the body and the tubing
- Burnishing reduced continuous pore structures and creates a long seal



Swagelok advanced geometry plus hardening process results in superior tube grip

SAT 12 Surface Carburization Technology

- Low-temperature carburization of rear ferrule
- Patented Swagelok surface hardening process
- Tool steel-like hardness
- Enhanced corrosion resistance
- Improved wear resistance
- Retained ductility



Fittings: FK Fitting Technology

Designed for Hydrogen

Reliable leak-tight installation and reassembly

- Gas seal in small molecule applications
- Vibration resistance
- Tube grip

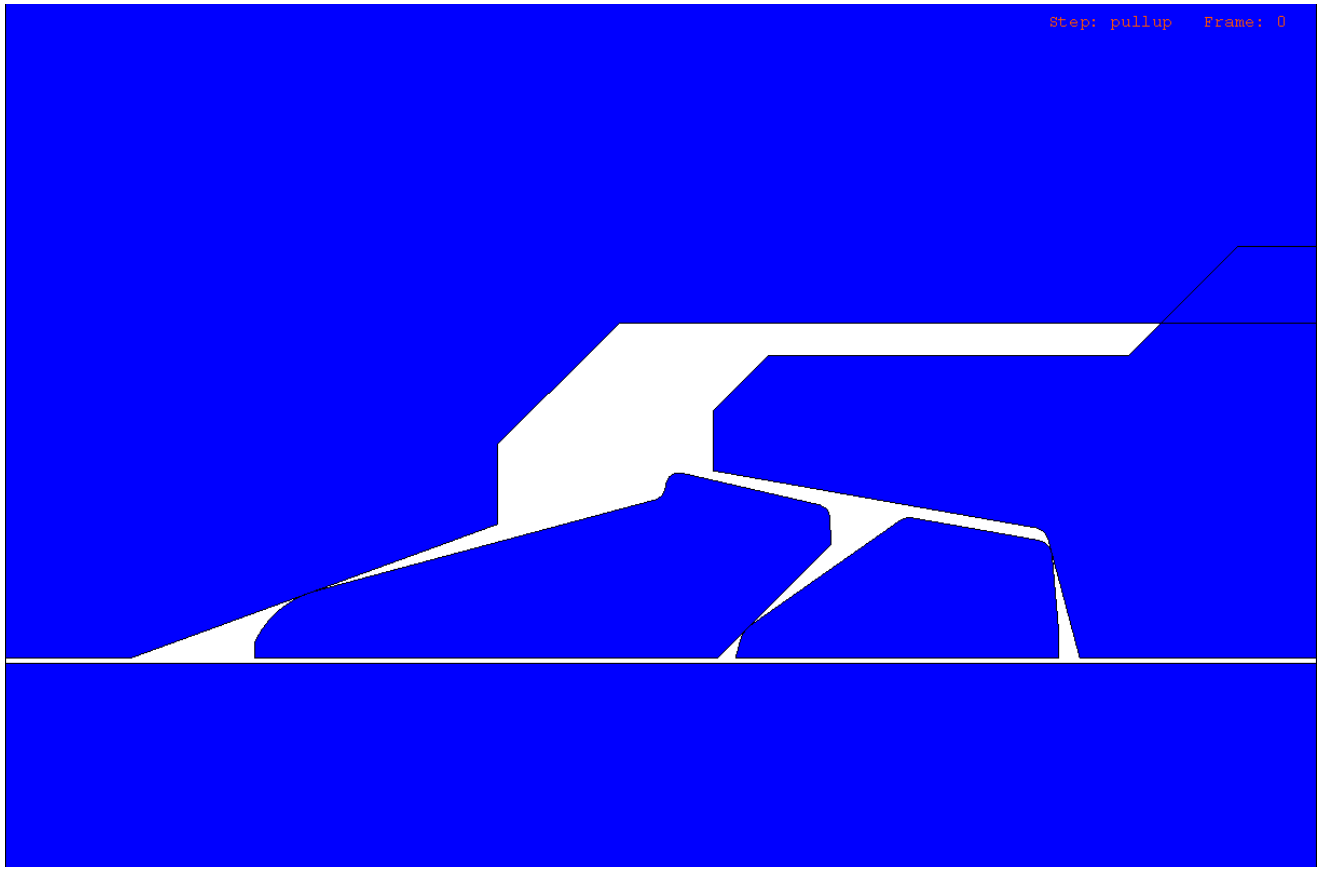
Quick and easy installation

- Assembly by one full turn or by torque
- Gaugeable

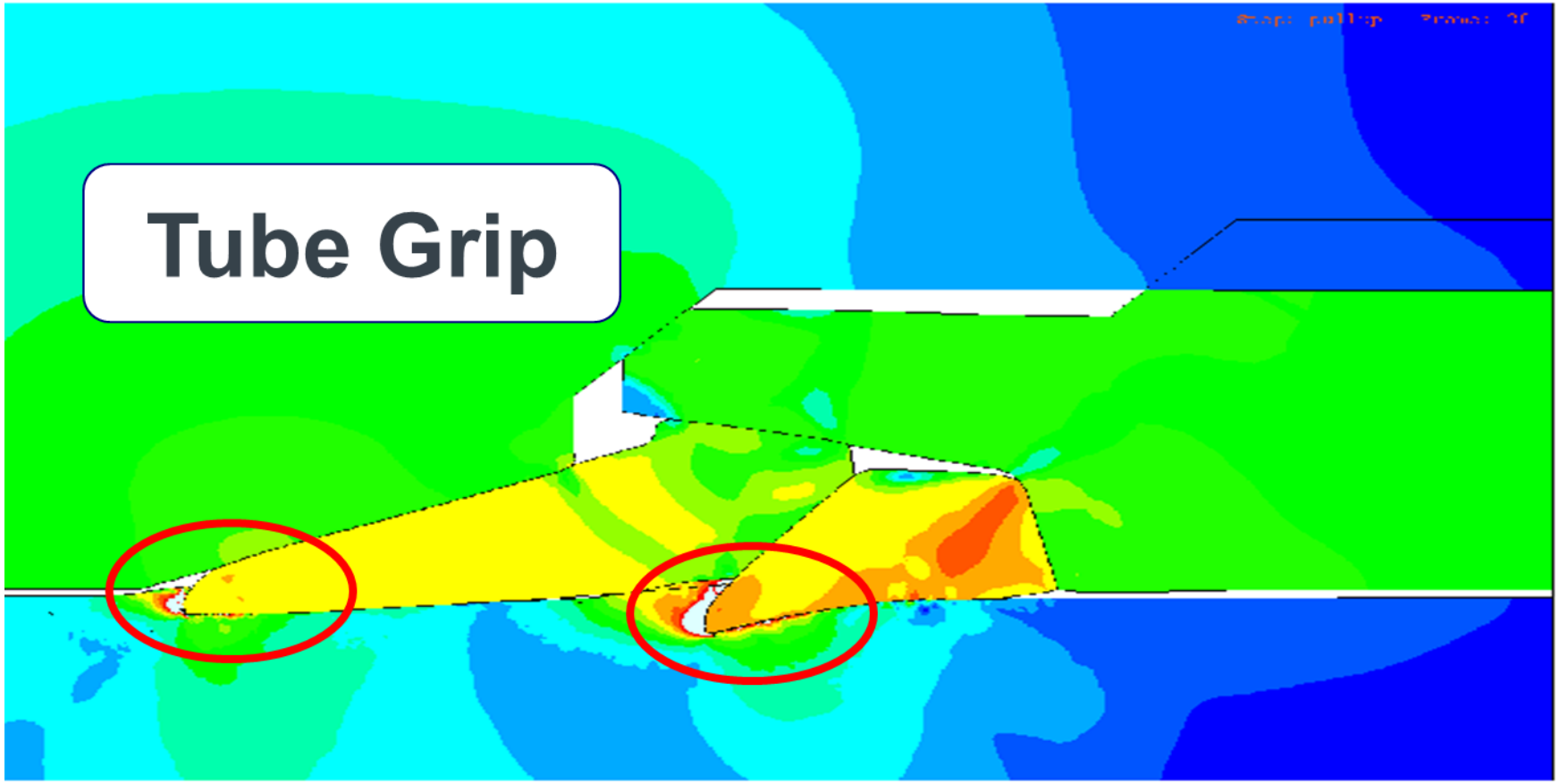
Variety of tubing options

- 316SS cold-drawn 1/8-hard tubing
- 316SS heavy-wall annealed tubing

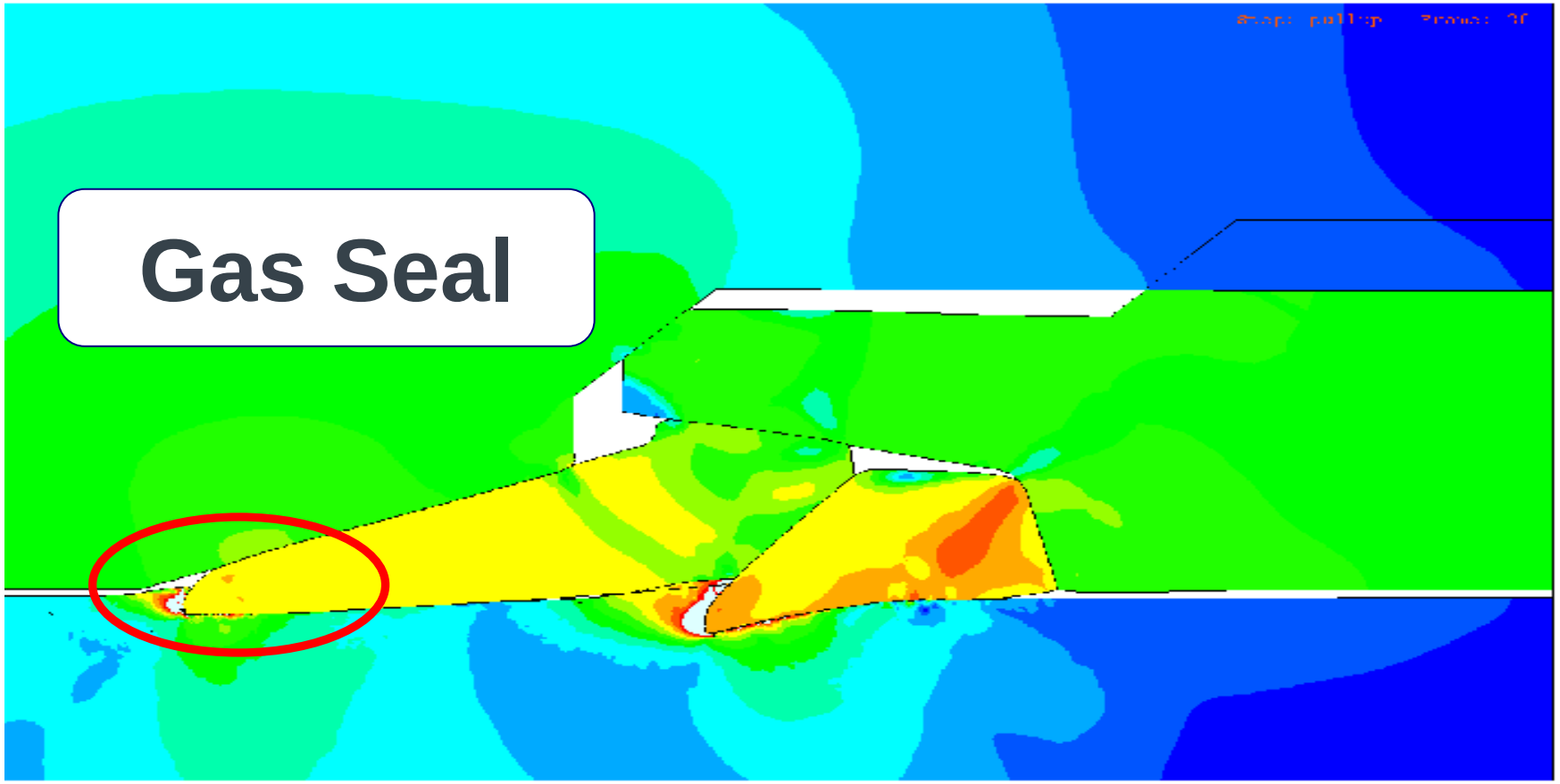
FK tube fitting hinging and colleting action



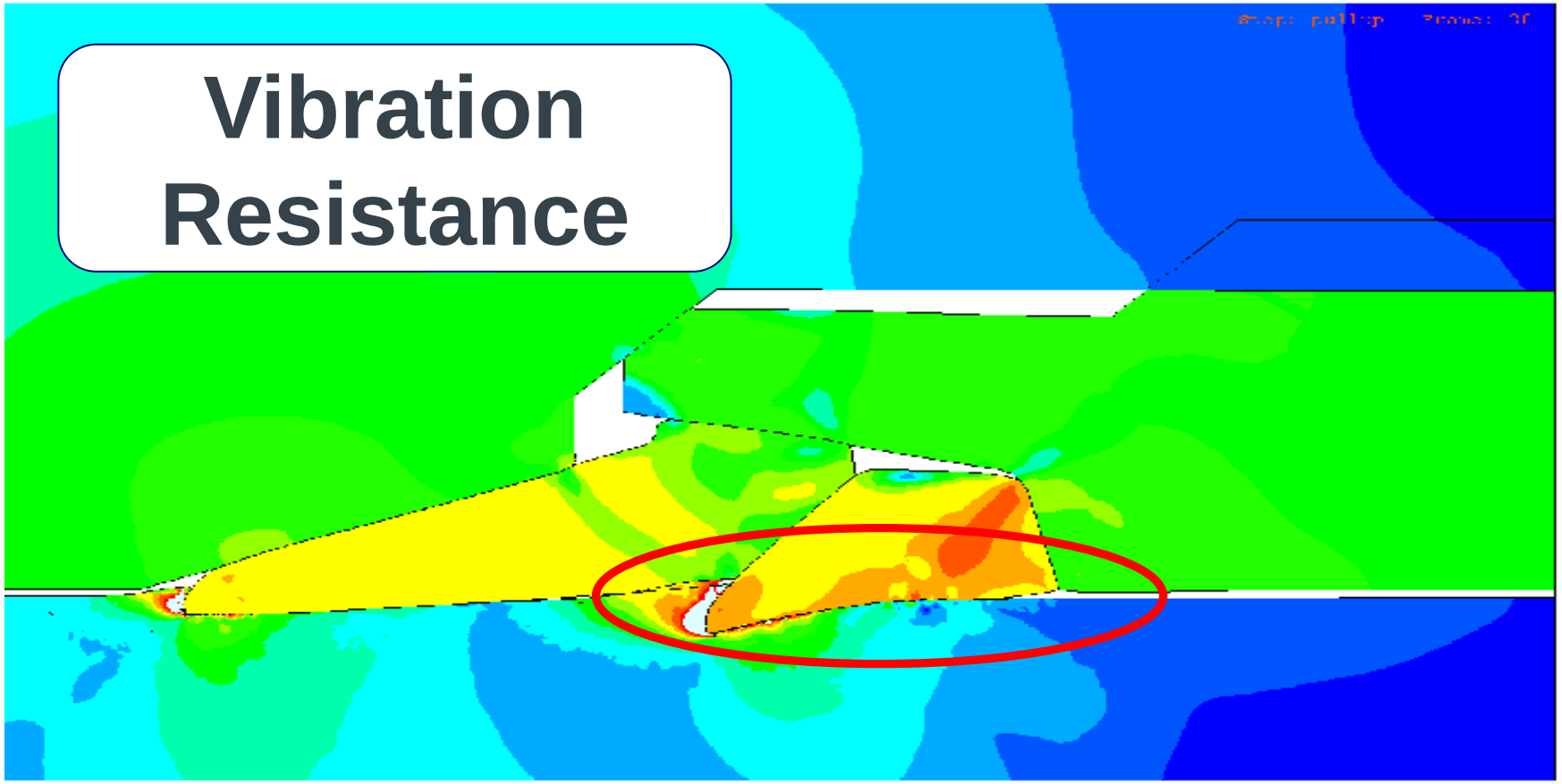
Stronger tube grip with twin grip action



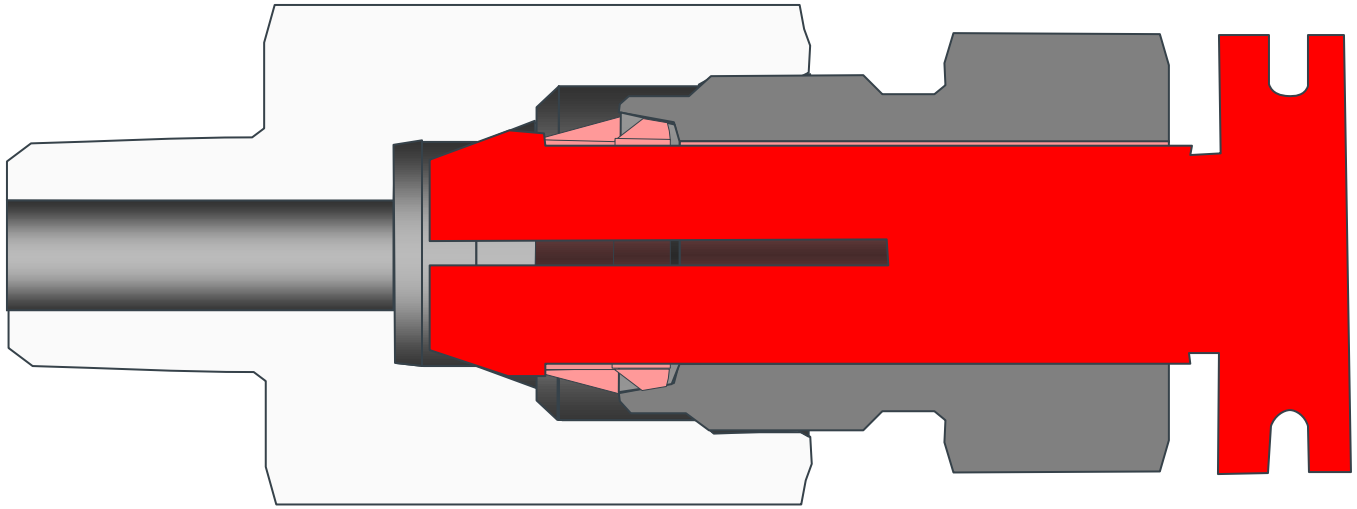
Better gas seal with burnishing action



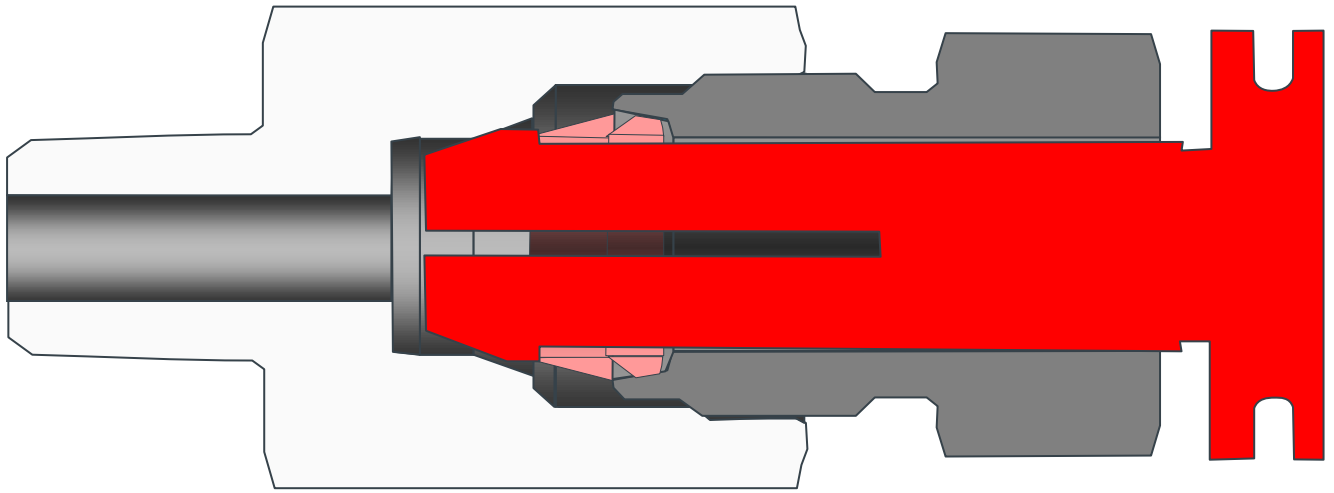
Reduce damaging effects of system dynamics with hinging and colleting action



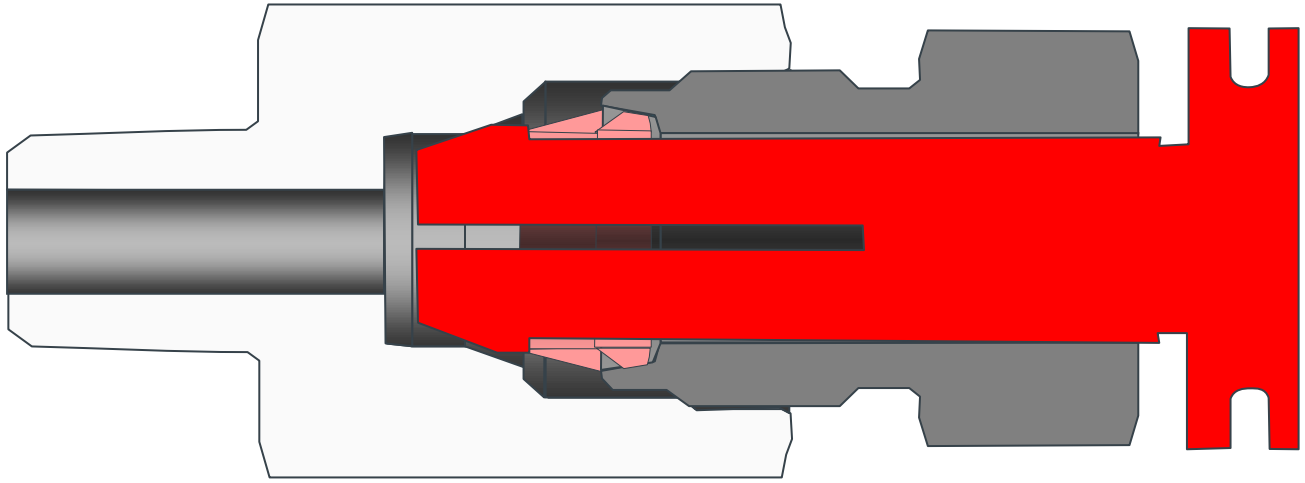
Patented Cartridge Assembly



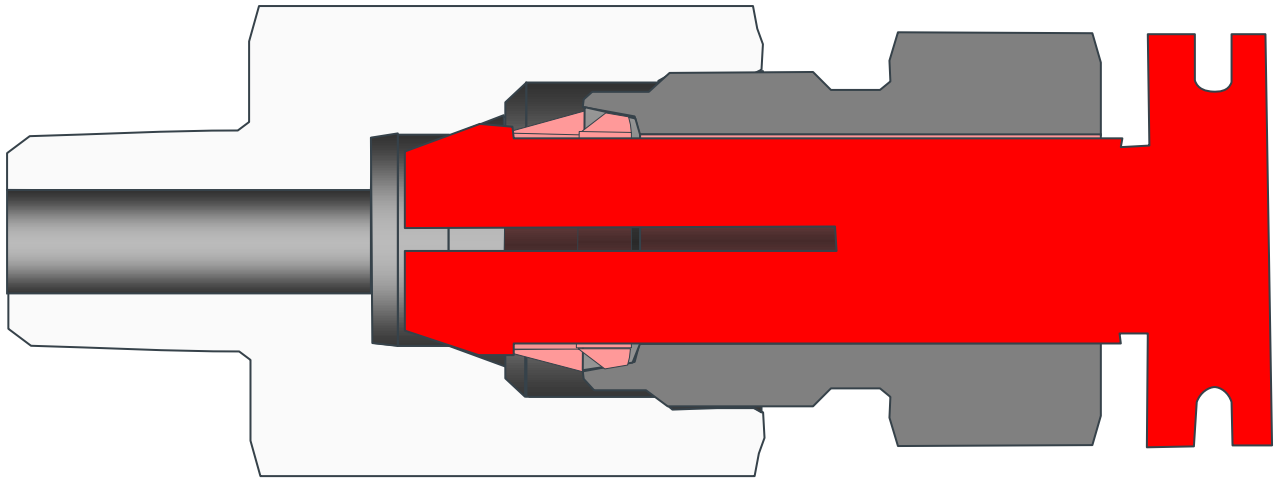
Patented Cartridge Assembly



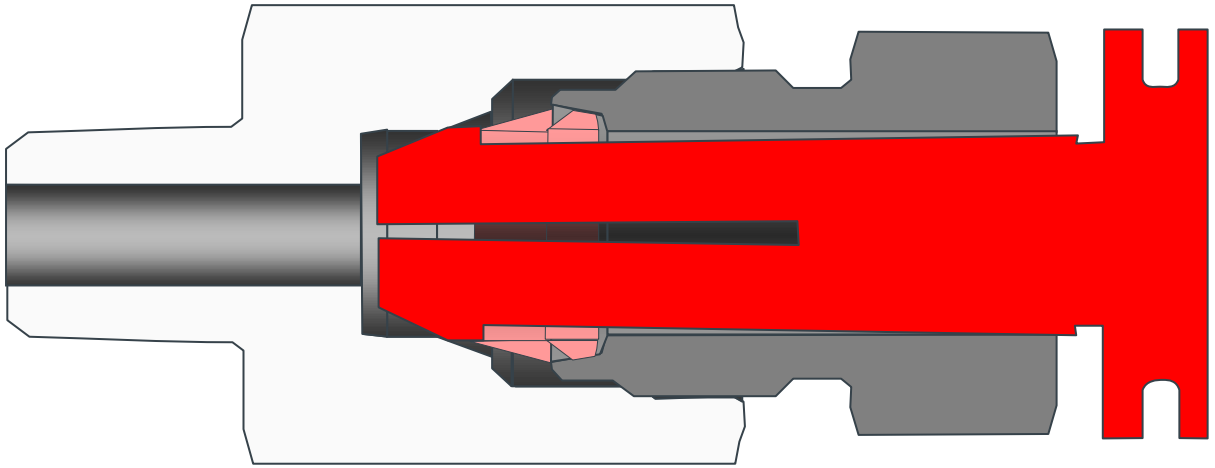
Patented Cartridge Assembly



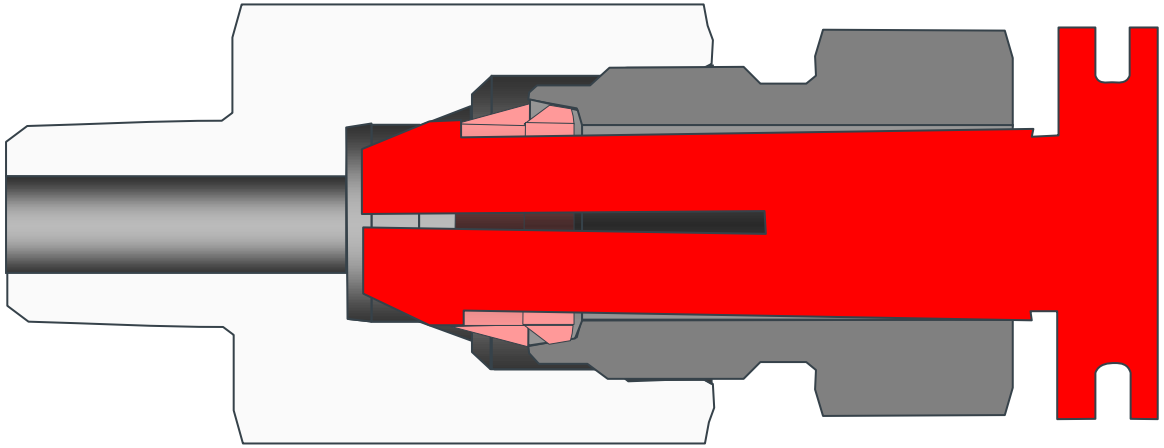
Patented Cartridge Assembly



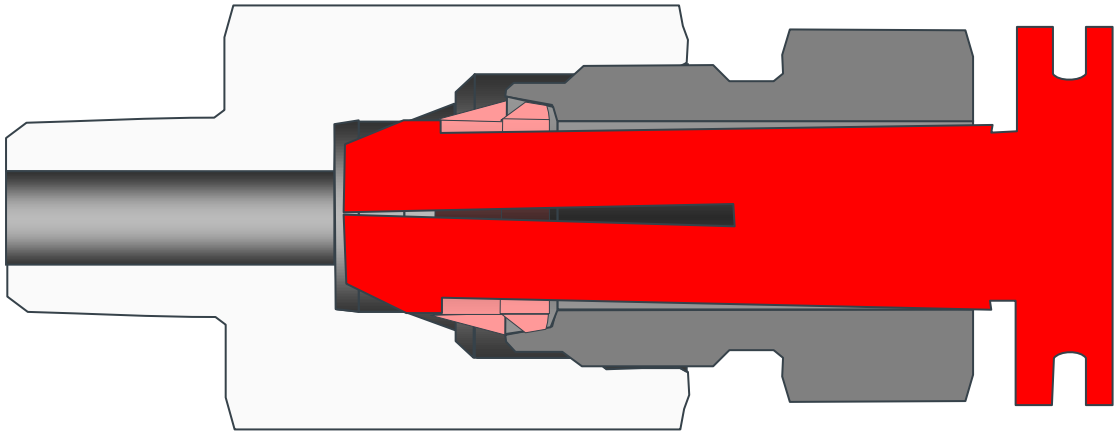
Patented Cartridge Assembly



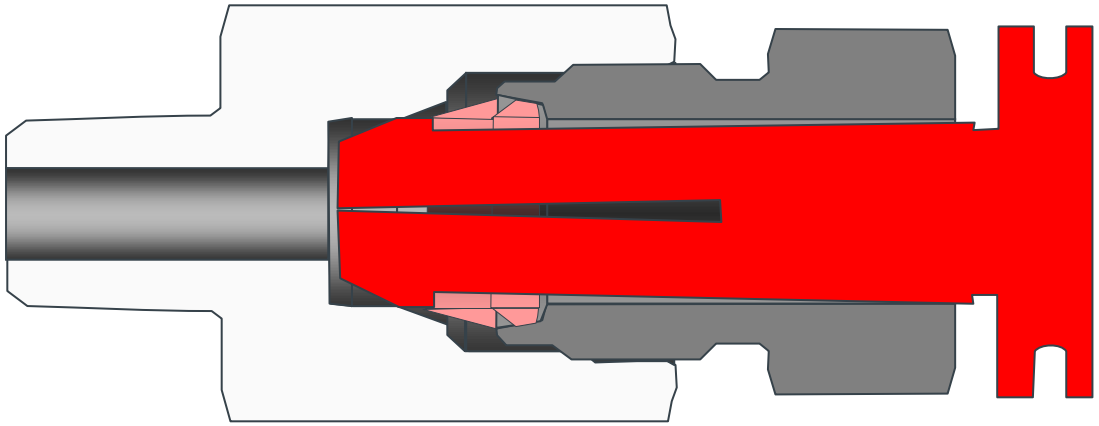
Patented Cartridge Assembly



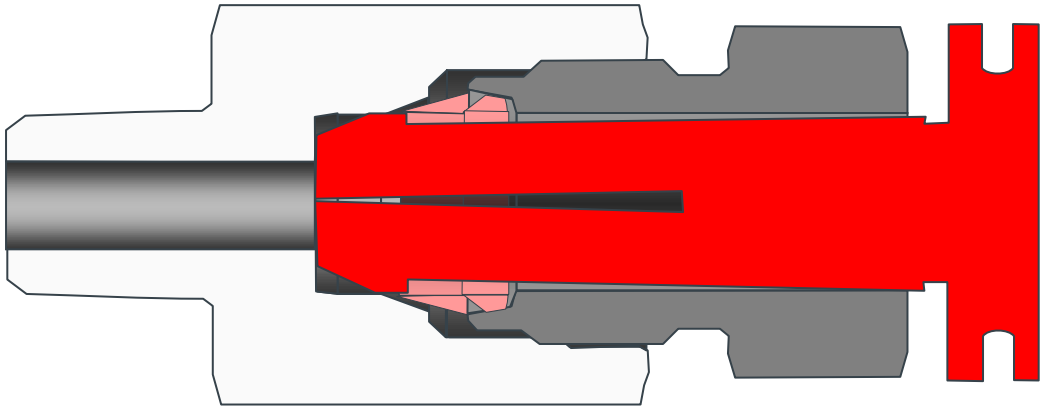
Patented Cartridge Assembly



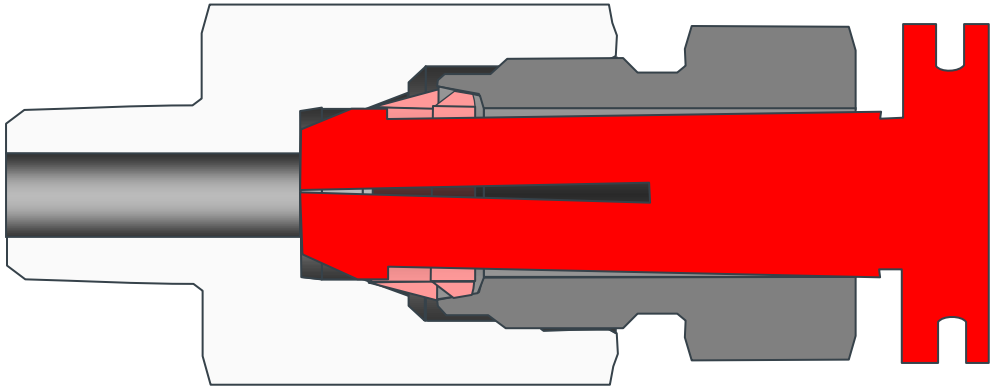
Patented Cartridge Assembly



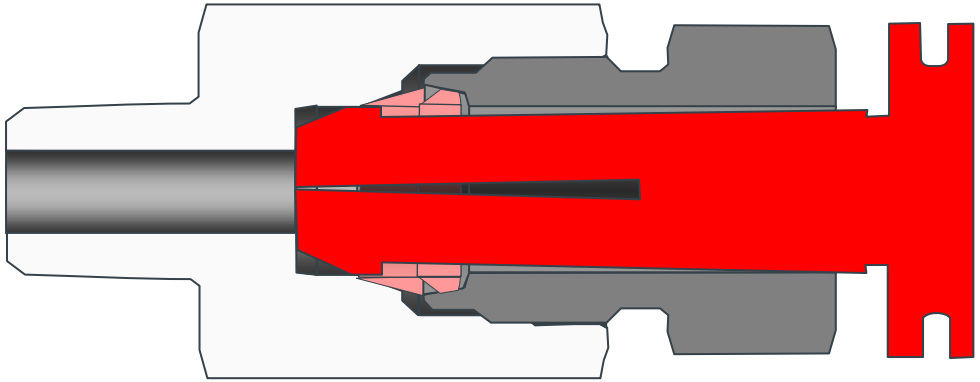
Patented Cartridge Assembly



Patented Cartridge Assembly



Patented Cartridge Assembly



Fittings for H_2: Swagelok FK Series

FK series fittings deliver these essential performance characteristics

- Seal tightness
- Grip strength
- Vibration resistance
- Material integrity
- Ease of installation

FK series fittings are available for your hydrogen fuel system needs.

Designed for Hydrogen