NATIONAL FLUID POWER ASSOCIATION
NFPA

Technology Task Forces

Preventing Leaks in Fluid Power Systems

Task Force Report

DECEMBER 2025

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BACKGROUND

As defined in the 2023 NFPA Technology Roadmap, many machine-level technology trends are actively shaping the future of the fluid power industry. These trends include the increasing electrification, connectivity, and autonomous functionality of mobile and industrial machines that use fluid power in their power or control systems.

In September 2023, NFPA launched two Technology Task Force teams, one focused on Mobile machinery and the other on Industrial machinery. Their task was to better understand these trends and engage stakeholders across the supply chain in developing the resources and connections needed to keep fluid power positioned as an actuation technology of choice on mobile and industrial platforms.

The Mobile Task Force identified several projects that would help it fulfill this mission, including:

- **Leak Prevention Task Force:** Produce a comprehensive report that summarizes current best practices for preventing leaks, assesses the prevalence of those practices across the industry, and estimates the potential for improvement based on actionable strategies and challenges identified through industry input.

The Task Force met multiple times to discuss this project, to share information and resources, and to develop a set of responses and recommendations. This report concludes the Task Force's final consensus, published in December 2025.

DESIGN CONSIDERATIONS

1. Application Factors

Component Accessibility: System components should be as accessible as possible to facilitate installation and subsequent maintenance. Containment trays should be incorporated where the probability of spills during maintenance is high.

Provisions for Extreme Temperatures: High or low temperatures in either the hydraulic fluid or individual components can cause degradation of seals and distortion of sealing surfaces or gland dimensions, resulting in leakage. Design provisions should be made to prevent damage due to thermal shock, and cold start procedures should be devised, whenever the potential for such conditions exists.

Material Compatibility: Corrosive environments may require the use of special materials or plating's, such as stainless steel, to prevent chemical damage to sealing surfaces. All materials shall be compatible with the type of fluid being used and the operating environment of the system, to avoid leaks due to seal, conductor, or other component degradation.

Provisions for Bleeding Air from Lines: To ensure that external leaks are observed immediately, system design should include provisions for bleeding air from the circuit after initial installation or at start-up following service. Such provisions may include prescribed procedures for cycling the system, incorporation of automatic air bleed valves, and designated vent points to allow air escape. Frequent loosening and tightening of connectors reduce sealing reliability.

Fluid Contamination: Excessive fluid contamination will result in premature component and seal wear, leading to external leakage. Wipers or other exclusion devices may be beneficial in applications exposed to very harsh environments.

Clean Assembly Practice: Initial component and system cleanliness are crucial, to avoid leaks at startup and during initial operation. Ensure that components are free of chips and burrs. See 4.4 for conductor cleaning guidance.

Lubrication: Lubrication of the threads is highly recommended on steel connections and is essential for stainless steel and high-pressure connections. If not lubricated, stainless steel will often gall between threaded connections, preventing adequate tightening and resulting in leakage. Retightening of high-pressure stainless-steel connections is not recommended without relubrication.

2. Component Selection

Components for a hydraulic system shall be selected to meet the performance parameters of the system. The selection and application of fluid connectors and conductors is extremely important for preventing external leakage. The ports and connectors referenced in this standard typically have a pressure rating not exceeding 40 MPa (6,000 psi).

Port Selection: Two types of ports are recommended: straight thread O-ring boss ports (figures 1 and 2) or bolted flange ports (figure 3). Both use O-rings to seal between the ports and mating conductors. Several designs of each type are in wide use. The following paragraphs describe preferred examples.

NOTE: Tapered pipe threads are not recommended for hydraulic systems due to poor sealing reliability.

Straight threaded ports (ISO 6149-1 or ISO 11926-1): Ports in accordance with ISO 6149-1 and ISO 11926-1 have straight threads, an O-ring seal surface and a surface for engaging the face of a mating stud end. Ports and stud ends in accordance with ISO 6149 and ISO 11926 are the preferred configuration for threaded ports because they can reliably result in a zero-leak connection.

Thread sizes in ISO 6149 range from M8 x 1 to M60 x 2. Thread sizes in ISO 11926 range from 5/16-24 to 2 ½-12. Both ISO 6149 and ISO 11926 specify working pressures and the related burst and cyclic endurance (impulse) test pressures to be used to verify working pressures.

ISO 6149-1 ports are identified by a raised ring, as illustrated in figure 1, or by permanently marking" metric" or "M" next to the port, or by a permanent identification label on the component to read" ISO 6149-1 metric ports."

Non-adjustable (see figure 1) and adjustable (see figure 2) stud ends are available in both ISO 6149 and ISO 11926 configurations.

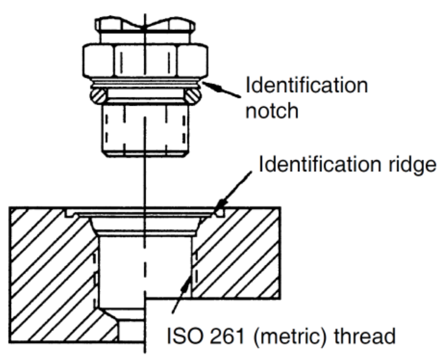


Figure 1 — O-ring Boss Straight Connector with Non-adjustable Stud End

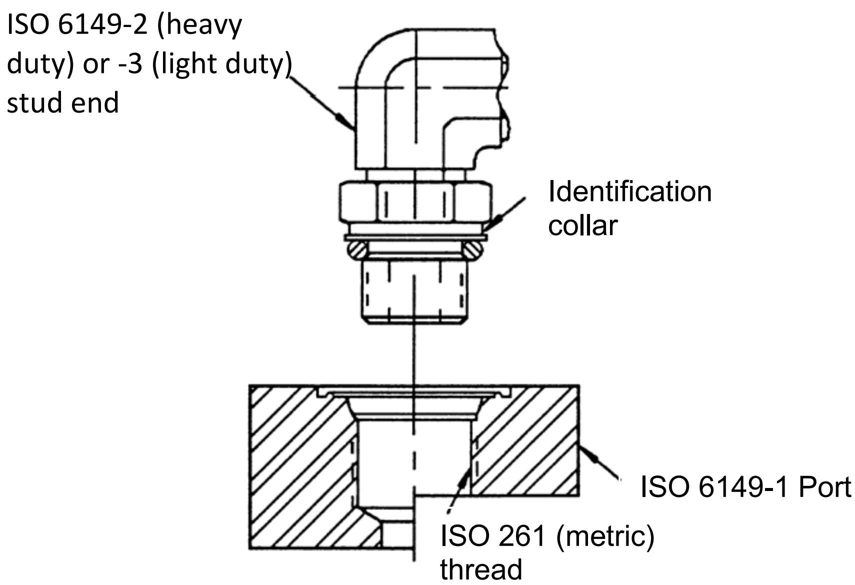


Figure 2 — O-ring Boss Elbow Connector with Adjustable Stud End

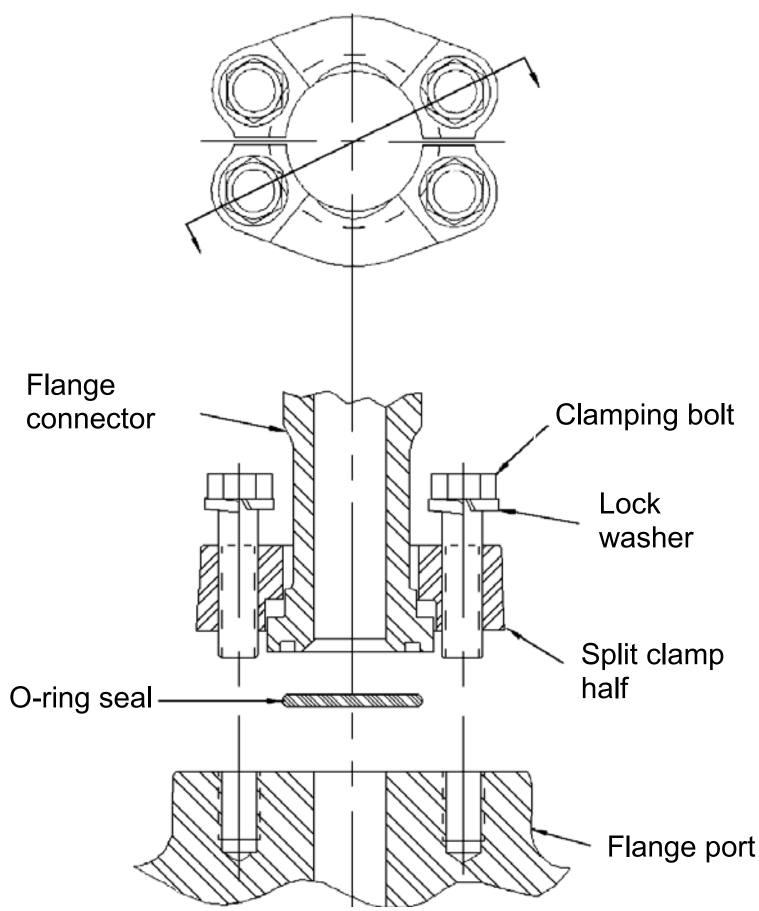


Figure 3 – Split Flange Port

Flange port (ISO 6162 or SAE J518): Split flange connectors take more space than threaded connectors but are easier to install. Sealing of the connection is accomplished with a single elastomeric O-ring as shown in figure 3. ISO 6162 contains dimensional and screw thread data for both metric (type 1) and inch (type 2) series. ISO 6164 describes a four screw, one-piece flange. New designs should follow ISO 6162 or 6164, using metric threaded fasteners.

Tube Connections: There are several types of tube connections available. The preferred styles are described in this paragraph. The pressure ratings of tubing recommended for use with these connectors are given in SAE J1065 and ISO 10763.

O-ring face seal connector (ISO 8434-3 and SAE J1453): The O-ring face seal connector uses an elastomeric seal that seals on the flat face of the sleeve (see figure 4). It is available in SAE dash sizes -4 through -24 (SAE J1453) and sizes for use with tube outside diameters from 6 to 38 mm (ISO 8434-3).

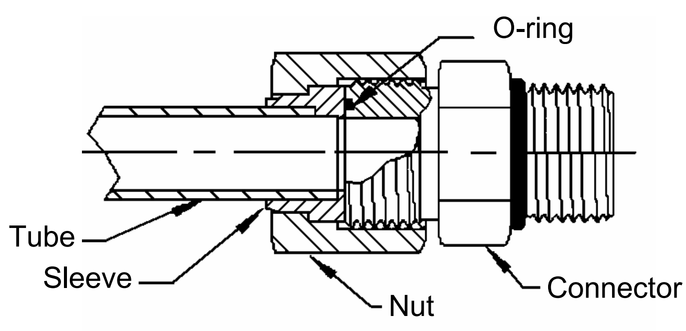


Figure 4 — O-ring Face Seal Connector Assembly

Table 1 – Characteristics of O-ring Face Seal Connector

Advantages	Disadvantages
Seal reliability	Larger envelope size
Positive assembly feel	Temperature range limited by seal
No tube entry. Can be laterally placed for easier installation	O-ring fallout is possible
No tube thickness limitation	Brazing or flanging equipment is required
Highly resealable	Size 2, 3, 5 and 14 tubes require special sleeves
Adaptable to metric tubing	Difficult to bleed air

37°-flare connector (ISO 8434-2 and SAE J514): 37° flare connectors seal on the inside of the flare with a metal-to-metal seal or with a compliant material between the nose of the connector and the surface of the tube (see figure 5). Connectors for flared tubing are available in SAE dash sizes -2 through -32 (SAE J514) and sizes for use with tube outside diameters from 6 to 50 mm (ISO 8434-2). Both SAE J514 and ISO 8434-2 specify working pressures, and ISO 8434-2 specifies the metric version of the connector.

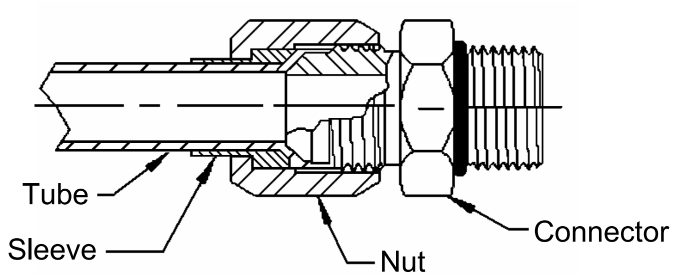


Figure 5 — 37° Flare Connector Assembly

Table 2 – Characteristics of 37° Flare Connector

Advantages	Disadvantages
Wide temperature range	Metal-to-metal seal
Small envelope	Installation is torque sensitive
Adaptable to metric tubing	Over-tightening can damage sealing surface
Worldwide availability	Not suitable for heavy wall tubing
	Requires flaring equipment

24° Cone Connectors (bite-type connectors) (ISO 8434-1 and SAE J514): 24° cone connectors use a metal ferrule to grip the tube and seal between the tube and body of the connector (see figure 6). They are available in sizes -2 through –32 (SAE J514) and sizes for use with tube outside diameters from 4 to 42 mm (ISO 8434-1).

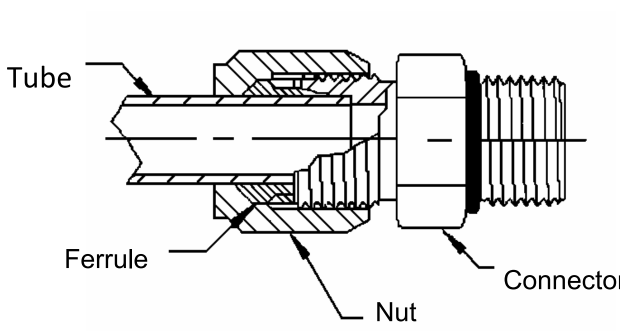


Figure 6 – 24° Cone Connector Assembly

Table 3 – Characteristics of 24° Connectors

Advantages	Disadvantages
Small installation envelope	Not suitable for thin wall tubing
Requires a minimum amount of tube preparation	Susceptible to installation errors
Not limited in temperature range by a seal	Difficulty in achieving a tight metal to metal seal

Flanged Connectors (ISO 6162, ISO 6164 and SAE J518): Flange connectors seal on the face of the connector with an O-ring, as shown in figure 3. They may be joined to tube, hose or pipe. Some of their advantages and disadvantages are outlined in Table 4.

Table 4 – Characteristics of Flanged Connectors

Advantages	Disadvantages
Reliable seal	Large envelope
Small assembly clearance	Multiple components
High-pressure capability	Subject to assembly sequence error
Readily available	Temperature range limited by seal
Accepts standard wrenches	O-ring fallout is possible

3. Hose Fittings

Several types of hose fittings exist. The popular styles are described in the following subclauses.

Crimped or Swaged Hose Assemblies: In this type of assembly, the hose is permanently attached to the hose fitting by swaging or crimping the hose between an outer shell and an insert, as depicted in figure 7.

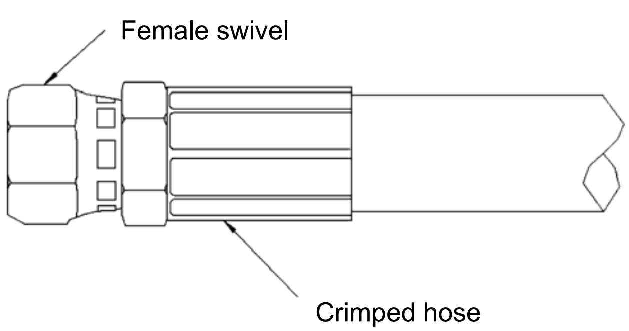


Figure 7 — Crimped Hose Assembly

Table 5 – Characteristics of crimped or Swaged Hose Assembly

Advantages	Disadvantages
High reliability	Needs special assembly equipment for each manufacturer's coupling
Small envelope	Couplings are not reusable
Customizable length	Crimp diameters must be closely controlled
More flexible than tube or pipe	Hose insertion depth must be controlled
	Hose can store energy when pressurized due to accumulator effect

Screwed Hose Assembly: In this type of connection, the hose is attached to the hose fitting by threading a socket onto the hose followed by threading the stem into the socket. (See figure 8).

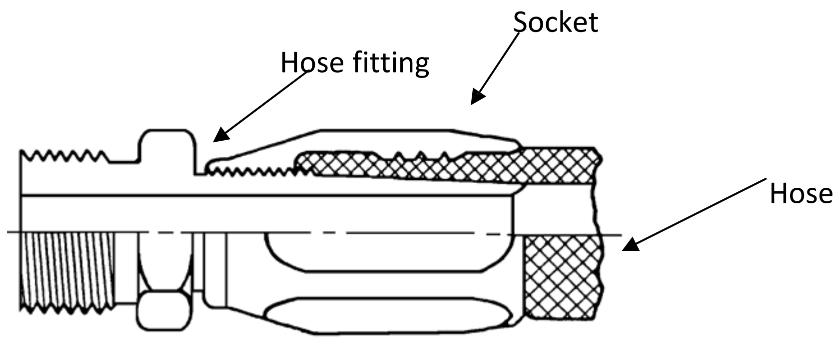


Figure 8 — Screwed Hose Assembly

Table 6 – Characteristics of Screwed Hose Assembly

Advantages	Disadvantages
No special equipment is needed	Large envelope size
Hose fitting is reusable	Limited selection available
	Requires high torque in large sizes

4. Fluid Conductors

Overview

The type of fluid conductor, (hose, tubing or pipe), should be based on application parameters. Hose is the clear choice if relative motion must be accommodated. Steel tubing is the best general-purpose choice unless relative movement of the ends is involved. Steel and stainless tubing is also better suited for high temperature applications.

Clamping both hoses and tubes is often necessary to limit vibration and deflection under operating load, to help keep sealing connections tight. Figures 9 through 13 show recommended clamping schemes.

Clamping and shielding should be used to protect flexing hoses from abrasion or fatigue damage and to prevent any hazards to people should leaks occur. Hoses that flex under load should be inspected regularly and replaced at any indication of a problem.

Tube Selection: Tubing in accordance with ISO 3305 and SAE J525 are recommended for most applications. SAE J1065 and ISO 10763 are recommended guides for selecting tubing wall thickness. Copper tubing is not recommended for hydraulic applications because of the potential for work hardening with pressure fluctuations. Certain hydraulic system operating and/or environmental conditions may require the use of stainless steel or aluminum tubing. When stainless steel or aluminum tubing is selected, connectors of the same material shall be used.

Hose Selection: Refer to SAE J517 for hose selection guidelines.

Pipe Selection: Galvanized pipe shall not be used as the fluid conductor, as there is potential for chemical reactions between the zinc galvanizing and certain hydraulic fluid additives.

5. Fluid Conductor Routing

Overview

Routing needs to be considered early in the design stage of a machine. Improper routing is a major cause of leakage. Arrange conductors for ease of assembly and maintenance (see figure 9).

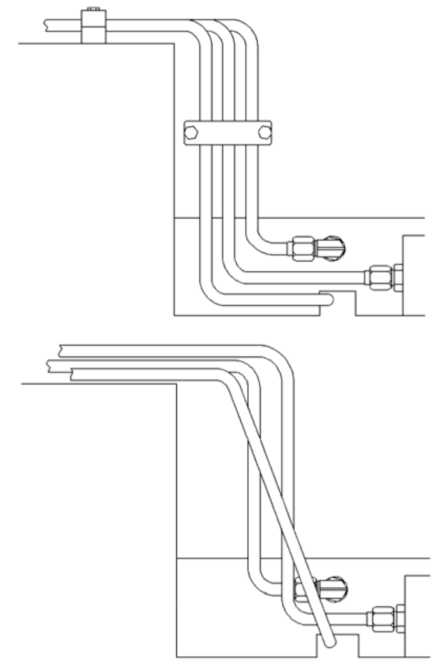


Figure 9 — Maintain Component Accessibility for Ease in Assembly and Maintenance

Tube Routing and Installation: Tubing should be bent whenever possible to reduce the number of connectors. Follow the manufacturers bend radius recommendations. Tube assemblies should align with the center line of the connectors. Tubing should not be sprung into position to be assembled to connectors (see figure 10). Rigid lines should have allowances for expansion or contraction due to hydraulic pressure changes, thermal differentials and mechanical tolerances between parts by using “S” bends or loops. Avoid straight line tube connections, especially in short runs, and use bends to compensate for variations in tube lengths (see figure 11).

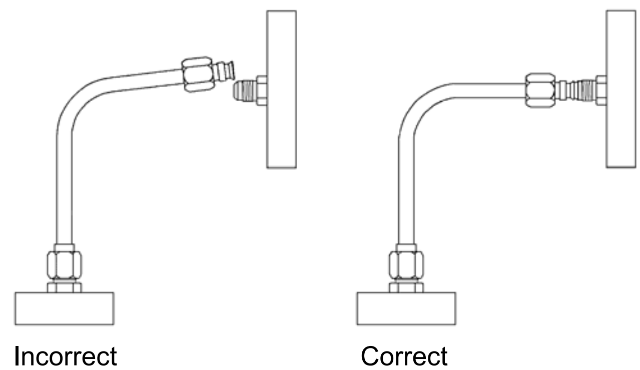


Figure 10 — Tube Alignment

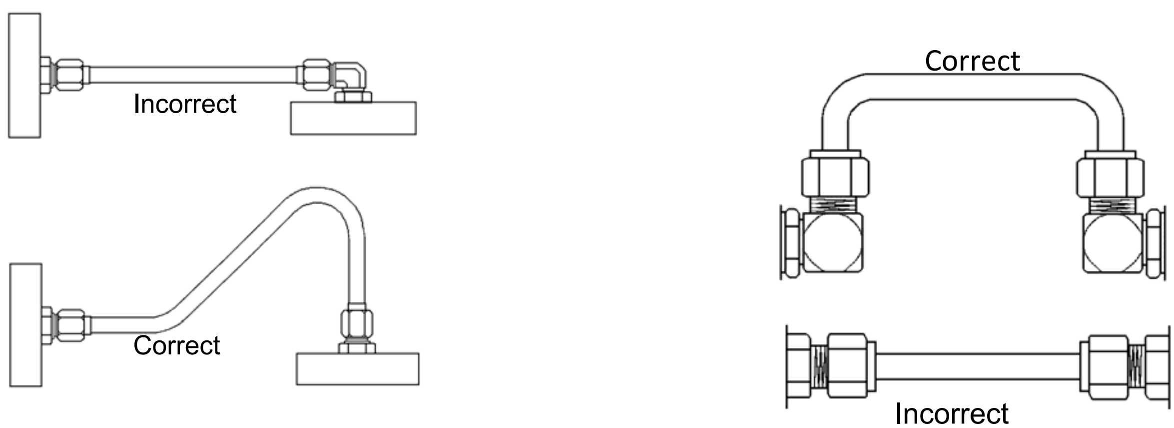


Figure 11 — Tube Installation

Tube Clamping: Use proper clamping to limit deflection due to vibration. This will reduce tubing fatigue and leakage due to loose connectors. See figure 12 and table 7 for general recommended clamping practice guidelines.

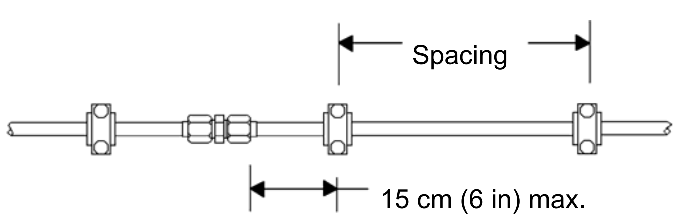


Figure 12 — Recommended Tube Clamping

Table 7 – Recommended Tube Clamp Spacing (see figure 12)

Tube OD	Maximum spacing
6.4 to 12.7 mm (1/4" to 1/2")	0.9 m (3 ft)
15.9 to 22.2 mm (5/8" to 7/8")	1.2 m (4 ft)
25.4 mm (1")	1.5 m (5 ft)
31.8 mm and larger (1 1/4" and larger)	1.8 m (6 ft)

Hose Routing: Under pressure a hose typically changes in length from -4 % to +2 %. Provide sufficient slack in the hose. SAE J1273 and ISO/TR 17165-2 recommended practices for hose routing should be followed.

When hose lines pass near a hot surface, a heat-resistant sleeve or a metal baffle should insulate them. Brackets and clamps are recommended to reduce abrasion of hose or the mating structure. See figure 13.

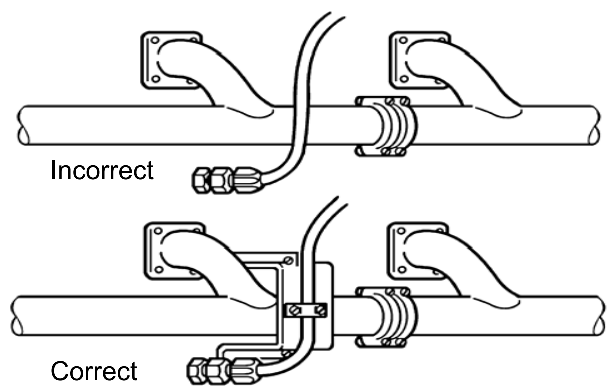


Figure 13 — Conductor Shielding from Harsh Environment

In applications that may result in considerable hose flexing, such as cylinder installations having clevis or trunnion mountings, allow ample hose length to prevent kinks and overstressing. The hose minimum bend radius shall not be exceeded during any portion of cylinder movement. See the example in figure 14.

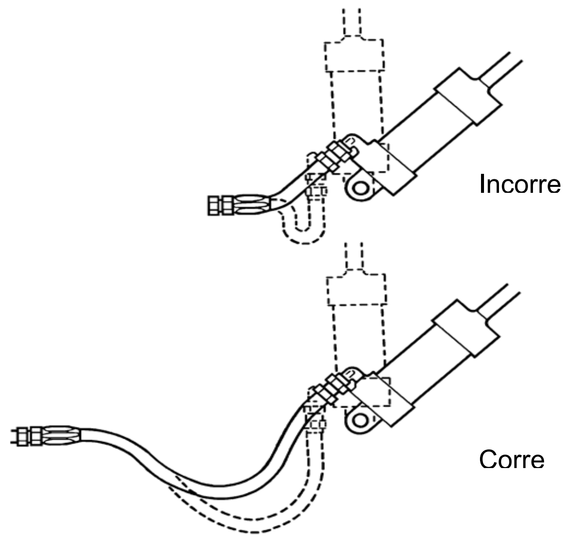


Figure 14 — Proper Hose Length to Allow Movement and Flexing

ASSEMBLY PROCESSES

Overview

Good installation methods and practices are essential to complement a good design in preventing leakage. See *ANSI/(NFPA) T3.19.25 R1* for guidance in storage, handling, and installation of elastomeric seals and exclusion devices.

1. Port installation

All sealing surfaces should be inspected for cleanliness, surface finish and damage of the seal area, alignment, and general quality (for example, no hanging burrs). The condition of threads in ports and connectors is especially important. Do not remove protective caps and plugs until the connection of the specific components is ready to be made.

Materials, surface finish, coatings and lubricant affect the required torque on threaded joints. Use torque values recommended by the connector manufacturer.

Straight thread port (ISO 6149 or SAE J1926): O-rings should be examined for fit and lubricated with system fluid or a compatible lubricant prior to installation. Install the O-ring on nonadjustable connectors using a thimble on the threads. Screw the connector into the port and torque properly. Install adjustable fittings per the procedure described in SAE J2593.

Split Flange Port (ISO 6162 or SAE J518)

To properly assemble split-flange connectors:

a) Clean all mating surfaces.

b) Lubricate the O-ring with system fluid.

c) Using the sequence shown in figure 15, apply 50 % torque on the first pass, then 100 % on the final pass. Use torque values recommended by the manufacturer or in the appropriate SAE or ISO standard.

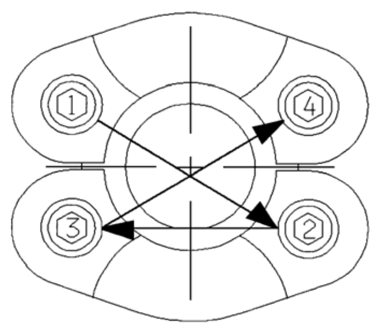


Figure 15 — Split Flange Bolt Torquing Sequence

2. Tube Installation

Overview

Good tube installation depends on proper tube preparation and tube bending.

Tube preparation: The tube end shall be cut square within ± 1° (see figure 16). The inside diameter and outside diameter shall be properly deburred and cleaned.

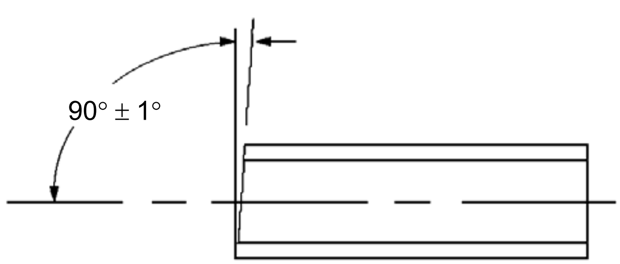


Figure 16 — Tube Preparation

Face Seal Connectors (refer to ISO 8434-3 or SAE J1453): The brazed joint between sleeve and tube shall be uniform completely around the tube. Braze overflow onto the O-ring sealing surface of the sleeve shall be prevented. The sleeve sealing surface shall be square within ± 1° of tube centerline (see figure 17).

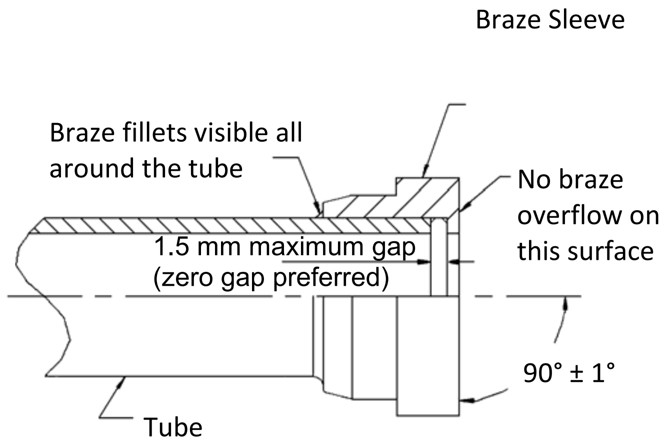


Figure 17 — Brazed Sleeve for O-ring Face Seal Connector

When connecting face seal connectors, it is important that sealing surfaces be cleaned and free from burrs. Dry assembly is normally preferred, since excess lubricant on threads can give a false indication of leakage. Use installation torques recommended by the connector manufacturer or the appropriate SAE or ISO standard.

Several mechanical joints are also available. Refer to the manufacturer's literature for proper assembly and reliable operation.

Flared Connectors (refer to ISO 8434-2 and SAE J514): The flare on the tube shall be smooth without burrs, splits, embedded particles, or other imperfections. It should conform to the guidelines listed in SAE J533 or ISO 8434-2. See figure 18.

One cause of leakage in flared connections is excessive assembly torque, which damages the sealing surfaces. Even with the correct torque, a connector that is fully tightened, loosened and re-tightened may begin to leak due to cumulative damage. Compliant inserts for use between the male and female portion of the connector are commercially available and may be of value.

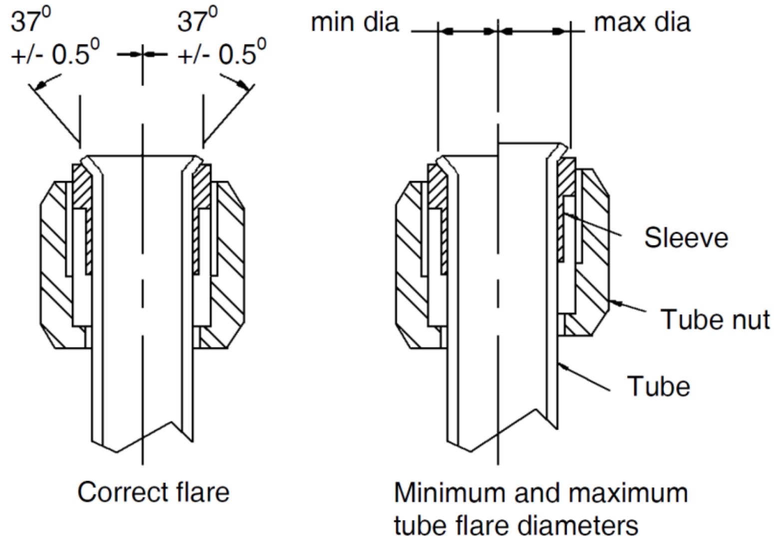


Figure 18 — Critical Flared Tube Features

Bite Type Connectors (refer to ISO 8434-1 and SAE J514): Figure 19 shows a properly preset ferrule of a bite type connector. For proper assembly and reliable operation of this type of connector see the relevant standard and the manufacturer's literature.

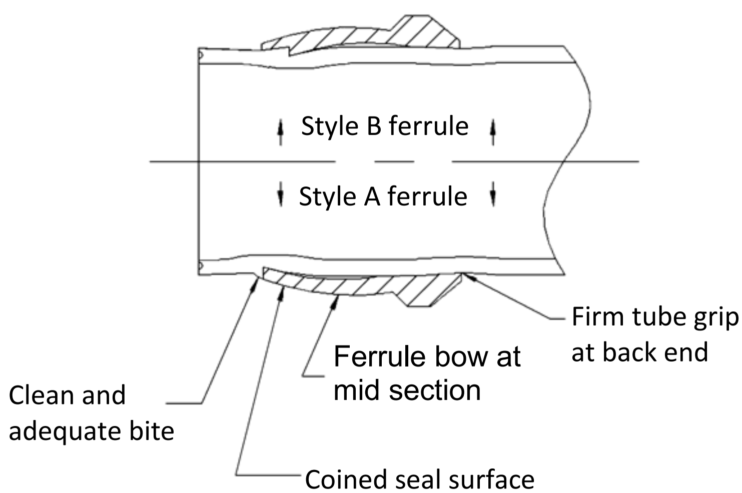


Figure 19 — Properly Preset Ferrule of Bite Type Connector

3. <u>Pipe Installation</u>

Good pipe installation depends on proper pipe preparation and bending.

Pipe Preparation: The pipe ends shall be cut square, as depicted for tubing in Figure 16. The inside diameter and outside diameter shall be properly deburred and cleaned.

Connector Installation: Typically, butt or socket weld flanges will be attached to the end of the pipe. Use ASME or AWS welding procedures applicable to the type of material, the joint design, and the operating pressure.

4. <u>Conductor Cleaning</u>

Overview

Tubes, pipes, and hoses are not clean, especially after preparing the ends and attaching the connectors. Therefore, they should be cleaned prior to installation into a hydraulic system. Several cleaning techniques are available, including blowing out the conductor with clean, dry air, using pneumatic projectile launchers, and flushing with an appropriately cleaned hydraulic fluid.

Cleaning with Compressed Air: Clean, dry compressed air works best on conductors with inside diameters smaller than 12.7 mm (1/2 in.) and lengths shorter than 0.9 m (3 ft.). The compressed air shall be significantly cleaner than the required cleanliness level for the conductor.

Cleaning with Pneumatic Projectiles: There are several commercially available pneumatic projectile launchers that are specifically designed for cleaning tubes, hoses, and pipes. Typically, this cleaning method is successful on conductors with inside diameters up to 25.4 mm (1 in.) and lengths up to 4.5 m (1.5 ft.).

Cleaning by Flushing Methods: A recommended cleaning method for conductors with inside diameters larger than 25.4 mm (1 in.) is flushing with a compatible fluid whose contamination level is at least two ISO 4406 code numbers cleaner than the required level for the fluid in the hydraulic system. The Reynolds number of the flushing fluid shall exceed 6000 to ensure turbulent flow for effective flushing. See ISO 23309 for further guidance.

REPAIR AND MAINTENANCE OF FLUID CONNECTORS AND CONDUCTORS

1. Locating the Source of the Leak

The true source of leakage shall be determined before attempting repair. Occasionally the location of an oil spot does not indicate the true source. Oil can run along conductors before dripping. To spot the leak point, clean the leakage area dry and watch for the leak to appear. After the leak is spotted, make sure oil is not dripping from above the joint. A black light or fluorescent dye in the fluid may be used as an aid in locating the source of the leak.

2. Determining and Eliminating Cause(s) of Leakage

DANGER: Investigate leaky areas with a probe to make certain a high velocity stream of oil is not present.

Leakage at Pipe Threads: Pipe threads are more prone to leakage than any other connection and are therefore not recommended. See Table 8 for some suggested remedies to address persistent leakage in properly tightened pipe thread connections.

Table 8 – Causes of and Remedies for Leakage at Pipe Threads

Cause of Leakage	Suggested Remedy
Cracked port	Replace defective component
Threads galled	Replace defective part(s)
Connector screwed in too far	Replace connector
No sealant	Apply sealant and re-torque
Severely nicked threads	Replace connector
Leaks when hot	Retighten when hot (not recommended for parts in castings)
Loose connector	Dampen vibrations through proper conductor supports or replace with straight thread port

Leakage at Straight Thread Connections with Elastomeric Seals: If leakage persists after the connector or locknut has been re-torqued properly, check for the potential causes listed in Table 9, and employ the suggested remedy.

Table 9 – Causes of and Remedies for Leakage at Elastomeric Seal Straight Thread Connections

Cause of Leakage	Suggested Remedy
Damaged, pinched, improper or missing O-ring	Replace O-ring and retighten to specification
Connector over-torqued (threads or undercut yielded)	Replace connector
Severely nicked or scratched port	Replace the port or replace the damaged component
Port spot face smaller than hex of the adapter	Re-machine port or replace the faulty component
Port threads distorted (yielded)	Replace component
Back up washer too loose	Replace connector
Excessive operating temperature	Revise system to reduce temperature Change to seals rated for higher temperatures
Elastomer – fluid incompatibility	Select seal of a compatible compound

Leakage at Four-bolt Flange Connections: If leakage persists at a four-bolt flange connection after proper retightening of the bolts, disconnect the flange and check for some of the potential causes listed in Table 10.

Table 10 – Causes of and Remedies for Leakage at Four-bolt Flange Connections

Cause of Leakage	Suggested Remedy
Pinched, damaged, improper or missing O-ring	Replace O-ring and retighten to specification
Nicked or scratched port face	Reface the port
Outer lip of flange severely nicked or scratched	Replace the part with the flange
Flange distorted	Replace the part with the flange
Clamp halves distorted	Use new clamps
Damaged fastener	Replace with new fasteners of appropriate strength
Excessive operating temperature	Revise system to reduce temperature Change to seals rated for higher temperatures
Elastomer – fluid incompatibility	Select seal of a compatible compound

Leakage at O-ring Face Seal End: If leakage persists after proper retightening of an O-ring face seal joint, disconnect the joint and investigate the possible causes listed in Table 11.

Table 11 – Causes of and Remedies for Leakage at an O-ring Face Seal Connections

Cause of Leakage	Suggested Remedy
Pinched, damaged, improper or missing O-ring	Replace O-ring and retighten to specification
Damaged (nicked or scratched) seal surface	Replace connector or sleeve
Tube not properly aligned with connector	Rebend tube for proper alignment
Faulty joint at sleeve	Rebraze or replace the tube or hose assembly
Flange severely nicked or scratched.	Replace the flanged part
Imbedded dirt, grit, burrs, etc. on the flange face	Replace the flanged part
Excessive operating temperature	Revise system to reduce temperature Change to seals rated for higher temperatures
Incompatibility between fluid and elastomers	Select seal of a compatible compound

Leakage at 37° Flare Connections: If leakage persists after proper retightening of the joint, disconnect the joint and investigate the possible causes listed in Table 12.

Table 12 – Causes of and Remedies for Leakage at 37° Flare Connections

Cause of leakage	Suggested remedy
Connector over-torqued or too soft (nose severely deformed)	Replace connector and tighten to manufacturer's specification
Embedded dirt, grit, burrs, etc. in the flare	Clean or replace tube
Severely scratched flare	Reflare or replace tube, or change to connector with compliant seal
Weld seam on flare	Replace with proper tube, or change to connector with compliant seal
Cracked flare	Replace tube
Lack of continuous (360°) flare contact on connector nose	Reflare or replace tube and/or replace connector
Spiral or axial scratched, nicks or chatter on connector nose	Replace connector, or add compliant seal
Tube not properly aligned with connector	Rebend tube for proper alignment

Leakage at a Flareless Connection: If leakage persists after proper retightening of a flareless joint, disconnect the joint and investigate the possible causes listed in Table 13.

Table 13 – Causes of and Remedies for Leakage at a Flareless Connections

Cause of leakage	Suggested remedy
Lack of clean and adequate bite	Check tubing for appropriate hardness in accordance with manufacturer's recommendation
a. Ferrule too loose (not preset enough)	If tube is acceptable, reset the ferrule to specification and inspect. If reset does not stop leak, replace tube assembly.
b. Tube too hard	
c. Tube not bottomed in connector during preset	
Tube collapsed excessively	Check manufacturer's recommendation for minimum tube wall
a. Tube wall too thin	If tube wall is acceptable, cut off the tube end and reset new ferrule per specification, or use new tube. If wall is improper, replace with proper tubing.
b. Ferrule too tight (over-set)	
Ferrule cocked on tube, tube not aligned properly with the connector	Replace tube assembly with proper bend for alignment.

Leakage at Hose/Hose Fitting Interface or in the Hose: If leakage occurs at the hose fitting or along the length of the hose, the hose assembly is either faulty or damaged. The only way to stop this type of leakage is to replace the hose assembly and take appropriate steps to prevent damage to the hose assembly (see 3.3). Excessive pressure spikes can cause hose to fail. Check the system for excessive pressure spikes and take steps to prevent them.

Leakage of a Tube: If leakage persists or continues to develop from a tube, investigate the possible causes and remedies listed in Table 14.

Table 14 – Causes of and Remedies for Leakage from a Tube

Cause of Leakage	Suggested Remedy
Tube split at bend: bent too tight or made with improper tooling or	Replace tube assembly with appropriately bent tube
System experiencing very high pressure peaks	Check system for pressure spikes, and take corrective action if necessary
Tube cracked circumferentially (fatigue crack due to excessive vibration)	Support tube appropriately to dampen vibration (See figure 11, 3.3.1)
Tube worn at a spot (tube rubbing against a hard object	Reroute tube to avoid rubbing

3. <u>Leakage Due to Abuse of Hoses, Tubes and Connectors</u>

Tube, hose and connector abuse is one of the major causes of leakage in hydraulic systems. Some of the common forms of abuse that should be avoided include:

a) Removing thread and seal surface protectors before actual use of the connectors.

b) Over-tightening of connectors at first sign of leakage. Over-tightening causes distortion of parts and possibly increases leakage.

c) Using conductor lines as structural supports such as a ladder, rails, etc. This causes strain in joints. Strained joints eventually leak.

SEALING OF HYDRAULIC COMPONENTS

Overview

Reducing leakage in hydraulic systems involves a combination of thoughtful seal geometry and material selection, precision engineering, and proper maintenance. These solutions are developed to meet specific application criteria like pressure, speed, and fluid type. There are several different sealing options available to increase reliability. Advanced materials like PTFE or polyurethane offer low friction and high wear resistance while minimizing leakage. Tandem sealing arrangements provide redundancy, enhancing sealing reliability. Adding back-up rings helps with higher pressures, adding bearings improves alignment, and including scrapers can reduce the likelihood of contamination entering the system and contributing to leakage. Additionally, maintaining optimal surface finishes on mating components and ensuring correct installation practices help prevent premature wear and leakage paths. These strategies for hydraulic system leakage control are described below.

Sealing Categories

Sealing of component elements is classified as static or dynamic. Static sealing systems prevent leakage between two parts having no relative motion. Dynamic seals prevent leakage between two machine elements having relative motion. With acceptance standards for performance and reliability rising, the term "sealing system" has been adopted to foster better understanding of the complexity of effecting a seal.

1. <u>Static Sealing Systems</u>

Overview

The O-ring seal between the head and bearing in figure 20 is a typical example of a static sealing system. To be effective, the seal shall be of the specified compound and size. Equally important, the sealing surfaces shall have proper finish and be free of blemishes and burrs. The lead chamfer shall also be free of burrs and blemishes to eliminate damage to the seal at assembly. Finally, care shall be taken not to damage the O-ring by abrading on the internal thread of the head during insertion. The cause of a static seal leak is often not due to the seal.

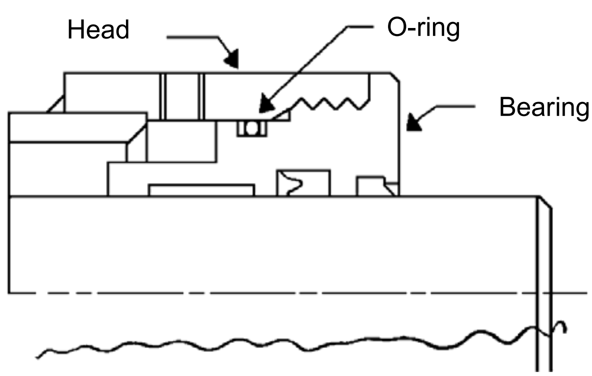


Figure 20 — Cylinder Rod Seal Assembly with O-ring

Gaskets: Another form of static seal is the gasket. It is an installation-activated seal and is made of relatively soft material. It seals by deforming under clamping load and filling irregularities of mating surfaces. Access covers for fluid reservoirs are frequently sealed with gaskets. Many different materials are utilized. Care should be taken to avoid overtightening gaskets.

O-rings: One of the most common seals is the O-ring. It is used extensively in hydraulic systems at all pressures. It seals by filling in small irregularities of mating surfaces. Caution shall be taken to assure that the proper compound and hardness are used. O-rings shall be compatible with the system fluid and the system operational parameters. When pressure levels increase, damage due to extrusion increases significantly (see figure 21). See the appropriate parts of AS 568 for O-ring and gland standards.

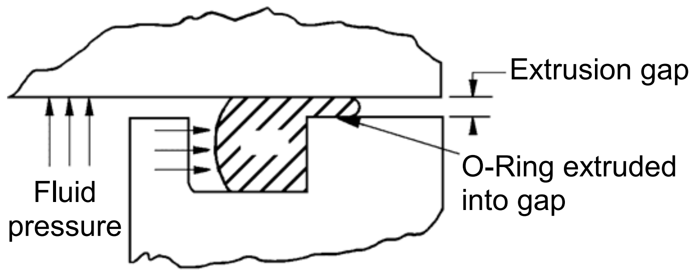


Figure 21 — O-ring Extrusion

Back-up rings (figure 22) can minimize extrusion and are required when pressures exceed 10 MPa (1,500 psi) or when looser manufacturing tolerances are required, creating larger extrusion gaps. At assembly, be certain the back-up ring is on the low-pressure side of the seal. When sealing pressures exceed 10 MPA (1,500 psi) from both sides, a back-up ring is required on either side of the O-ring. Be sure the gland width is sized properly.

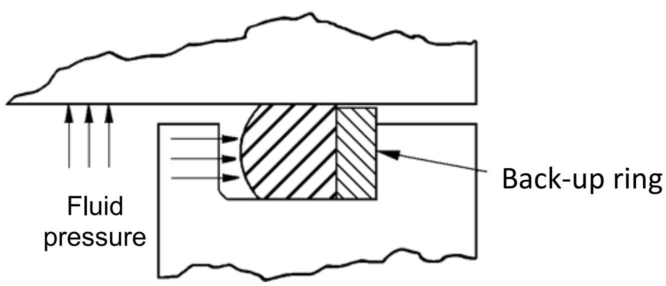


Figure 22 — O-ring with Back-up Ring

X-rings, Square-rings and Dualseals: Alternative static seal options are shown in Figure 23. These options are typically designed to fit O-ring grooves and offer better sealing. They can be used with back-up rings to minimize extrusion, except for the dual seal. The dual seal combines O-ring and back up ring features into a single seal which reduces the chances of twisting in the groove. X-rings generally provide higher seal efficiency and lower friction than O-rings. Square rings also have a higher sealing efficiency than O-rings and tend to retain their shape well.

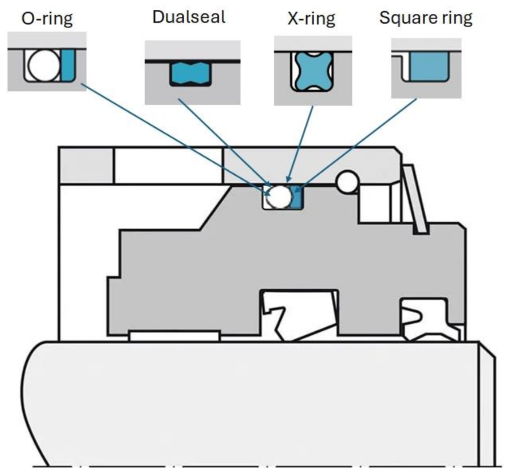


Figure 23 – Static Seal Options for Traditional O-ring

2. <u>Dynamic Sealing Systems</u>

Overview

Dynamic sealing systems may be classified into one of two categories:

a) Rotary (example: the sealing of a rotating pump or motor drive shaft.)

b) Linear (example: the sealing of a valve spool or cylinder piston rod.)

As described in the static seal example in 6.1 above, the cause of unsatisfactory performance is frequently something other than the seal.

Rotary Sealing Systems

Radial lip seals are often used as part of a rotary sealing system to retain fluids and exclude external contaminants at the interface between a rotating element such as a shaft and a stationary housing, such as a pump or motor case. Two common types of lip seals are:

a) Simple lip seal, which has an interference fit with the shaft

b) Lip seal with the sealing lip loaded against the shaft by a garter spring. This type provides a more positive seal, in that loading is more constant with wear of the seal lip (see figure 24 for one configuration).

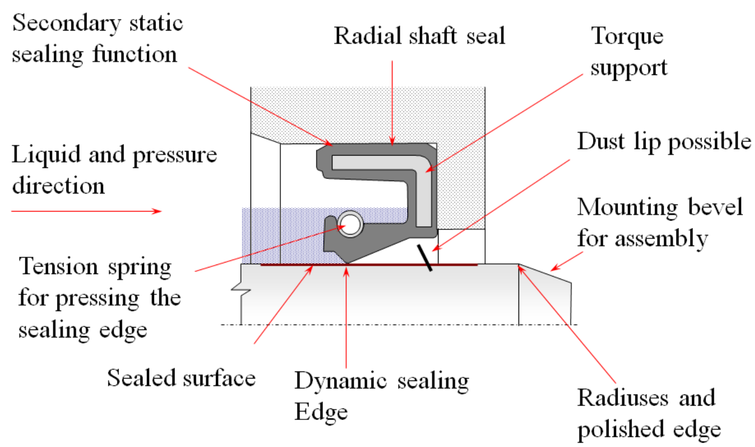


Figure 24 — Radial Shaft Seal with Garter Spring

Several materials are used today for lip seal elements. Material selection is based on the fluid to be contained, required operating temperature range, and desired system torque. The final selection is often a compromise that will satisfy most parameters. Sealing takes place at the contact area of the seal lip and shaft. Ideally, there is a very thin film of oil between the two. A thick film results in leakage. When the film is too thin, friction increases, raising the temperature, which accelerates deterioration of the seal.

Linear Sealing Systems

Linear sealing systems prevent or control leakage between surfaces that move axially relative to each other. Sealing of valve spools and cylinder rods are primary examples.

SELECTION OF CYLINDER SEALING SYSTEM ELEMENTS

The simplest of fluid power components, a cylinder with one moving part, the piston rod assembly, is probably the most complex to specify for optimum performance. Performance requirements such as life, durability, and response coupled with operational parameters such as velocity, fluid temperature, operating pressures, and side loads should all be considered in determining the elements of an acceptable sealing system. Such information should be available at the time of specification and design.

This section covers the more complex sealing systems typically incorporated in hydraulic cylinders to prevent external leakage at cylinder rods and to prevent ingression of foreign matter into the cylinder and eventually, the entire hydraulic system. The principal elements of a rod sealing system in a hydraulic cylinder are the rod seal, scraper or wiper, wear rings, and the piston rod, as illustrated in figure 25.

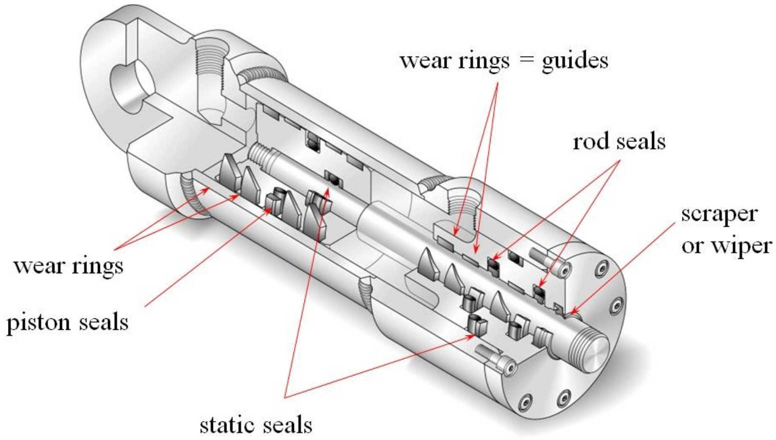


Figure 25 — Sealing Elements in a Hydraulic Cylinder

1. **Rod Seals**

The rod seal prevents an excessive amount of fluid from passing along the rod from the high-pressure side. Figure 26 depicts some of the many configurations or types of molded compression type and lip type seals that are available. Selection of the seal configuration should be based on performance requirements such as response and wear parameters (frictional properties) and leakage and life requirements.

Material selection should be based on fluid compatibility and operational parameters, such as fluid temperature and pressure, frictional properties, seal-ability, and durability. In high pressure applications, the sealing system may be comprised of a primary seal and one or more secondary seals to improve seal effectiveness and life. The secondary seals buffer the primary seal from the system pressure by dropping the pressure in steps as shown in figure 27.

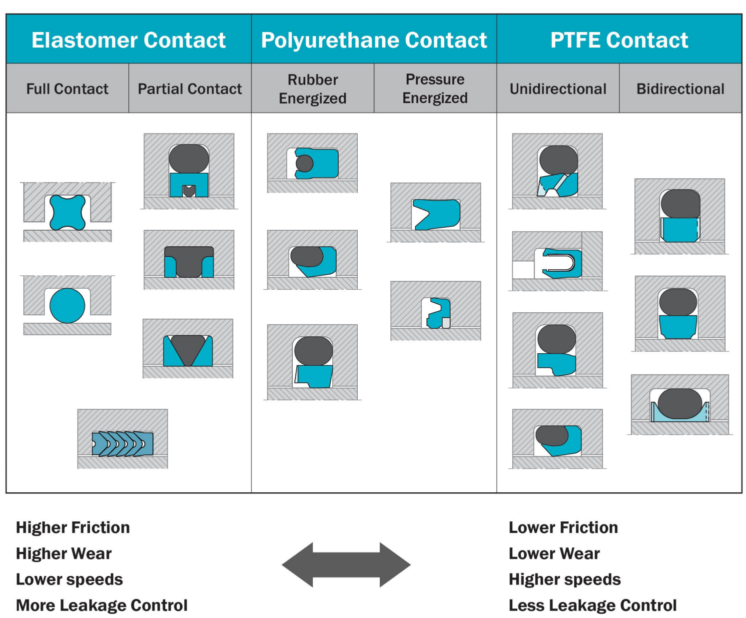


Figure 26 — Common Rod Seal Materials and Profiles

2. Rod Wipers

The primary purpose of the rod wiper is to prevent debris, dust or external fluids from entering the cylinder envelope and damaging the rod seal, which can lead to seal failure and contamination of the system fluid. Some wiper types perform a secondary low pressure sealing function by virtue of an inward facing second seal lip (figure 27). Care should be taken when using this type of wiper to avoid trapping pressure between the wiper and rod seal. Many alternative forms of rod wipers are available.

For hostile operating conditions where abrasive contaminants are present, it may be necessary to use a metallic scraper and a wiper in series. Rod wiper materials include bronze, beryllium, copper, all common elastomers, and plastics with elastomeric or spring energizers. Selection is based on environmental considerations, operational parameters, and performance requirements.

3. Bearings

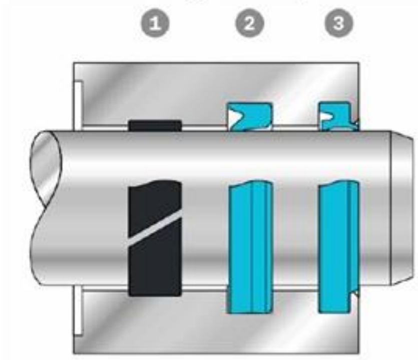
The function of the bearing is to support and center the rod. Low duty cycle applications may use only the cylinder head to support the rod, but more common is a single or double wear-ring arrangement (figure 27). Split bearings ease installation and repair, however disassembly of the cylinder is still required. Wear strips that fit into a groove in the head or cartridge are also popular bearings.

When a cylinder is rigidly mounted, and the load moved by the rod is externally guided, the piston becomes the support that centers the rod to the seals. The use of stop tubes (illustrated in figure 28) is important to prevent excessive side loads on the bearing in long stroke units that have unsupported loads or that are not rigidly mounted. Such side loads generate an eccentric condition, which accelerates bearing wear and early failure of the sealing systems.

Surface Finish: The functional reliability and service life of a linear sealing system is affected by the surface finish of the rod, cylinder bore, and ring grooves. Scoring, scratches, pores, concentric or spiral machining marks are not permitted on any sealing surface. With that said, higher demands must be made on the surface finish of dynamic mating surfaces than on static mating surfaces.

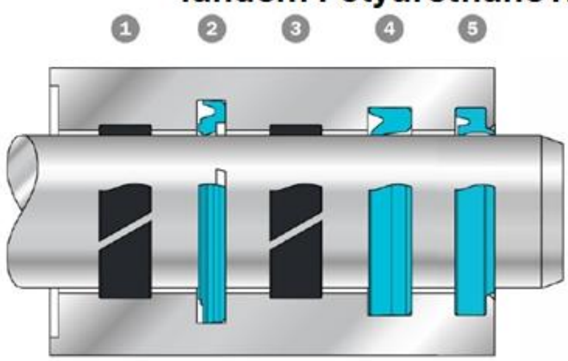
The characteristics most frequently used to describe the surface micro-finish Ra, Rp, Rz and Rmax are defined in DIN 4762 /ISO 4287-1. These characteristics alone, however, are not sufficient for assessing suitability of a surface finish in seal engineering. The relative material ratio (Rmr) must also be taken into consideration since it describes the specific profile form which is directly dependent on the machining process employed, and it is key to seal performance.

Single Polyurethane Rod Sealing System



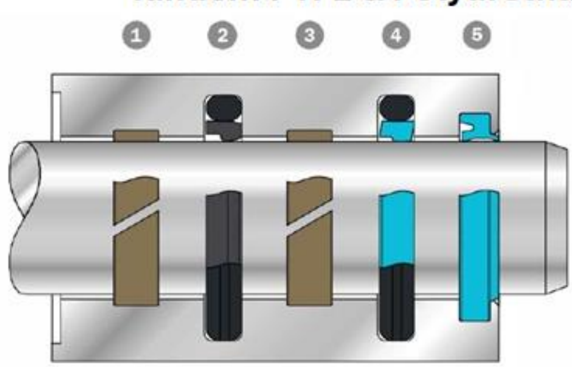
Position	Component	Material
1	Wear Ring	Acetal/POM
2	U-Cup	Polyurethane
3	Wiper	Polyurethane

Tandem Polyurethane Rod Sealing System



Position	Component	Material
1	Wear Ring	Nylon/Polyamide
2	Buffer Seal	Polyurethane
3	Wear Ring	Nylon/Polyamide
4	U-cup	Polyurethane
5	Wiper	Polyurethane

Tandem PTFE & Polyurethane Rod Sealing System



Position	Component	Material
1	Wear Ring	Filled PTFE/Composite
2	Cap Seal	PTFE
3	Wear Ring	Filled PTFE/Composite
4	Cap Seal	Polyurethane
5	Wiper	Polyurethane

Figure 27 — Common Rod Sealing System Components and Materials

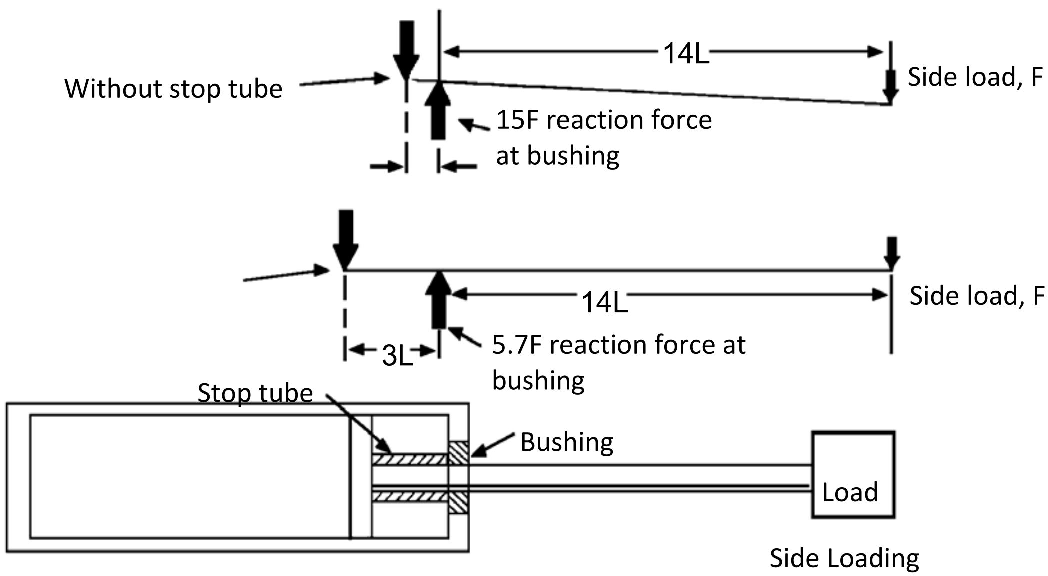


Figure 28 — Stop Tube to Reduce Bearing Loading

4. Cylinder Seal System Maintenance

In time, repair or preventive maintenance will be required to assure continued service. The best practice is to follow the maintenance instructions provided with the cylinder using the manufacturer's replacement parts.

Rigid mountings such as foot, flanged or extended tie rods, typically require no lubrication. Clevis, trunnion and self-aligning installations may require periodic lubrication if heavily loaded during operation, to minimize side loading due to friction. During overhaul, all static and dynamic seals and scrapers should be replaced. If elastomeric or plastic bearings are used, they should also be replaced.

The checklist in Table 15 may be helpful in evaluating cylinder components during maintenance and repair, and in troubleshooting sealing system deficiencies.

Table 15 – Cylinder Seal System Problems and Remedies

Component and condition observed	Suggested action or remedy
Piston rod – should be free of nicks, gouges, wrench marks or scratches	Replace if damaged
Bearing inside diameter and piston outside diameter – Heavy wear or burnishing on opposite sides (see figure 29) indicated side loading.	Check mounted alignment. Add stop tube.
Wear or heavy burnish on bearing, but little burnish on rod.	Change to higher performance bearing material
Seals soft or gummy	Check compatibility with system fluid
Seals hard or cracked	Check for high external heat source Check compatibility with system fluid
Seals extruded or deteriorated by heat	Check for excessive system pressure Check for worn bearing Check for excessive clearance between rod and bearing
Seals compressed or flattened, especially on one side	Replace Check for high temperatures Checked mounted alignment Check seal fit (compression)
Seals torn or nibbled	Replace Check for excessive clearance between rod/piston and housing Consider use of back-up rings Check seal fit. Seals may be moving excessively in the gland or getting pinched
Seals have spiral pattern of cuts	Replace Check seal fit. Seal may be moving excessively or rolling in the gland.

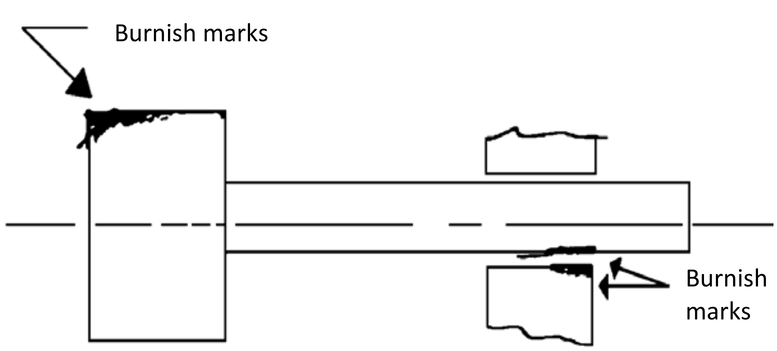


Figure 29 — Burnish Pattern from Side Loading

Follow the manufacturer's maintenance instructions for reassembly after repair or maintenance. The following precautions at installation can help avert the re-occurrence of leakage:

a) Clean and flush conductors and connectors before reconnecting cylinder. Remove cylinder port covers only at assembly of connectors.

b) Maintain the piston rod in the retracted position to prevent rod damage during construction or painting of machinery.

c) Carefully check alignment of piston rod to load attachment. When properly aligned, it will not be necessary to force mounting bolts, pins or the piston rod into position.

d) Allow time for elastomeric seals to recover from installation stretch before cycling the cylinder. Some plastic and bronze sealing elements may need to be resized or pressed into a gland after installation to facilitate assembly. Specialized resizing tools may be required.

e) Cycle the cylinder slowly and with no load if possible. This will purge the cylinder and system of air. Observe action for smooth operation. Listen for sounds that may indicate binding due to misalignment.

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ISO 261	ISO general purpose metric screw threads — General plan
ISO 3305	Plain end welded precision steel tubes — Technical conditions for delivery
ISO 4406	Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles
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SAE J517	Hydraulic Hose
SAE J518	Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt Split Flange Type
SAE J525	Welded and Cold Drawn Low-Carbon Steel Tubing Annealed for Bending and Flaring
SAE J533	Flares for Tubing

NFPA Leak Prevention Task Force
Survey Results

Introduction

As part of its ongoing mission to strengthen the fluid power industry, the National Fluid Power Association (NFPA) serves as a vital forum for collaboration among its members, OEMs, and technology partners. Within this framework, the NFPA launched a *Leak Prevention Task Force* in December of 2023, recognizing the importance of minimizing external leakage to improve hydraulic system efficiency, safety, and sustainability.

The *Leak Prevention Task Force* was tasked with producing a comprehensive report to:

1. **Summarize current best practices for preventing leaks**,
2. **Assess the prevalence of those practices across the industry**, and
3. **Estimate the potential for improvement based on actionable strategies and challenges identified through industry input**.

To achieve these objectives, the task force conducted a survey of NFPA members, encompassing a broad range of stakeholders in the fluid power industry, including suppliers, manufacturers, distributors, machine builders, and end-users. The survey explored perspectives on the impact of external leakage, the root causes of leakage, and the strategies deemed most effective for leak prevention. The results are presented below:

Survey Questions and Definitions

The survey consisted of targeted questions designed to capture the diverse viewpoints and experiences of NFPA members. Questions addressed organizational roles, market focus, and specific challenges and strategies related to external leakage. Respondents were also asked to evaluate the consequences and financial impacts of leaks on their operations.

Survey Questions for Leak Prevention Task Force

1) What is the primary role of your organization in Fluid Power Industry
    a. Component Manufacturer
    b. Equipment Manufacturer
    c. Distributor
    d. System Integrator
    e. User/other
2) What is your primary role in our organization?
    a. Executive management
    b. Sales or marketing
    c. Engineering
    d. Information technology
    e. Other

3) My organization serves the following markets?
    a. Mobile
    b. Industrial
    c. Both
4) Is external leakage a problem for your organization?
    a. Yes
    b. No
5) How significant are external leakage for your organization
    a. Low -> High in 5 increments
6) Which of these consequences of external leakage have the financial impact on your organization
    a. Downtime for repair
    b. Spill cleanup
    c. Safety (e.g. slips and falls)
    d. Fluid replacement and disposal
    e. Warrantee service
7) Which components are most susceptible to external leakage (please rank)
    a. Adapters and connectors
    b. Cylinders
    c. Hoses
    d. Manifolds
    e. Motors and Pumps
    f. Tubes
8) What are the most common mistakes people make that result in external leakage?

9) What is the greatest challenge to eliminating external leakage?

10) What strategy has the best potential for eliminating external leakage?

Summary of Survey Results

The survey respondents primarily consisted of component (46%) and original equipment manufacturers (34%), with engineers making up the majority (63%) of participants. Nearly all organizations served mobile markets (98%), while 37% also operated in industrial markets.

External leakage was reported as a problem by 76% of respondents, with its significance rated an average of 2.8 on a 1-to-5 scale. The most common cost impact was on customer satisfaction (95%), followed by downtime and repair costs (58%) and warranty expenses (53%). Connectors (68.4%) and hoses (47.4%) were identified as the components most frequently affected by leakage. These findings reveal that leak prevention is essential for customer satisfaction and market acceptance of fluid power technology.

Common Mistakes Leading to External Leakage

Respondents indicated that improper use of torque wrenches during assembly and repair, poor conductor routing and support, use of outmoded connectors, and failure to minimize connection points were common mistakes that lead to external leaks. Several noted that early intervention during the design phase, such as collaborating with sealing solutions companies and ensuring design-for-assembly principles, can significantly reduce leakage. On its face, it appears that all of these common mistakes are preventable.

Barriers to Solving Leakage Problems

Respondents identified several key barriers to addressing leakage problems, with many emphasizing the importance of proper training, including educating technicians on correct installation practices, torque specifications, and system maintenance. Design challenges were frequently mentioned, such as ensuring seal integrity, improving system design to withstand vibration, and minimizing connection points in confined assembly areas.

Material and component issues were also highlighted, including the durability of seals, quality of castings, and proper selection of system-rated hydraulic components. Several respondents pointed to systemic issues, such as cost-driven decision-making over technology, adherence to entrenched industry standards, and insufficient integration of advanced sealing technologies.

Additionally, respondents noted challenges in troubleshooting and diagnostics, such as identifying the root cause of leaks, verifying system integrity before shipment, and addressing customer misconceptions about leakage sources. Other barriers included external factors, such as contamination ingress, increasing duty cycles, and the high cost of implementing improved technologies.

These insights underline the need for better training, improved design practices, and strategic use of advanced components and materials to effectively mitigate leakage challenges.

Strategies with the Best Potential for Eliminating External Leakage

Respondents emphasized education and training as critical strategies, including better maintenance training, operator-independent assembly techniques, and enforcing the use of torque specifications in assembly and service manuals. Improved design practices were also highlighted, such as eliminating NPT and O-rings face seals in favor of bore-sealing joints.

Other strategies focused on preventing errors and damage, including eliminating installation damage, ensuring correct part usage, and using gland drains to monitor seal performance. Respondents also stressed the importance of clear communication and documentation, such as obtaining detailed technical data sheets and assisting customers in applying appropriate specifications.

These strategies collectively suggest that a combination of education, design optimization, and process standardization holds the greatest potential for reducing external leakage.

Raw Survey Results

1. Forty-one (41) respondents.
    a. Component manufacturer: 46%
    b. Equipment Manufacturer: 34%
    c. Distributor: 7%
    d. System integrator: 7%
    e. User/other: 5%
2. Role in organization
    a. Engineer: 63%
    b. Sales/marketing: 20%
    c. Executive management: 12%
    d. Other: 5%
3. Markets served
    a. Mobile: 98%
    b. Industrial: 37%
4. Leakage a problem for your organization?
    a. Yes: 76%
    b. No: 24%
5. Significance on a scale of 1 to 5:
    a. 2.8
6. Cost impact
    a. Customer satisfaction: 95%
    b. Downtime/repair: 58%
    c. Warrantee costs: 53%
    d. Safety/compliance: 29%
    e. Spill cleanup: 21%
    f. Fluid replacement: 16%
7. Components most effected
    a. Connectors: 68.4%
    b. Hoses: 47.4%
    c. Tubes: 44.7%
    d. Cylinders: 36.8%
    e. Manifolds: 36.8%
    f. Pumps/Motors: 31.6%

8. What are the most common mistakes people make that result in external leakage?
    a. Improper training
    b. Foundry design reviews. Seal design reviews.
    c. Reduce the amount of connection points and switch to connections with soft seals rather than mechanical seals.
    d. Not sure, perhaps a computer vision system of some sort, to properly identify when and where external leakage is happening.
    e. Push-to-connect is great but costly

f. Most effective seems to be handled at initial design. Designs that allow for easy implementation of best installation practices seem to reduce leak issues.
g. Systematic Standard Engineering.
h. Timely & Proper training to be provided to the Hydraulic fitter.
i. Critical Assembly areas & High-Pressure system to be taken care with intervention of trained supervisor.
j. Not sure
k. use the most appropriate/reliable fitting and ensure proper training
l. Preventive Maintenance
m. The biggest complaint I have seen regarding leakage is from the suction hose on refuse trucks. Contamination build up on the suction strainer will cause cavitation that may collapse the suction hose causing the tank to drain out onto the street.
n. Partnering with sealing solutions companies from the design phases.
o. Internal copper gaskets on tapered fittings.
p. I find that a lot of external leakage can be eliminated if there is a detailed review before the system is implemented and started - as all it takes is a single loose item to cause a mess.
q. Design for assembly.
r. Upgrading O-ring technology and installation torque.
s. Proper work instruction, Correct design/selection of components

9. What is the greatest challenge to eliminating external leakage?
    a. High quality green sand castings. Seal design.
    b. Having a full understanding of the system and how it will be used.
    c. End of line verification, prior to shipment.
    d. consistent tightening of connections
    e. greatest challenge is component integrity over time. Continuous vibration can eventually cause components to leak.
    f. Following Proper standards based on applications & Hydraulic system parameters.
    g. Use of System Rated Hydraulic Components based on requirement.
    h. Systematic Engineering Before Integration of hydraulic system.
    i. Skilled labor in Hydraulic fitter at assembly area
    j. Troubleshooting shaft seals. Leaking shaft seals are difficult to figure out why.
    k. Proper training and use of the proper fittings
    l. Shutting down the application to correct the problem.
    m. Avoid using NPT fittings and use hose guards or sleeves to protect from wear potential injury due to a leak.
    n. Mindset. “If it leaks, the seal is the problem”. The problem can be somewhere else. Design engineers should worry about their end product and leave the sealing design to the expert companies.
    o. Adequate combination of seal & torque

p. In most cases it is something which can be easy to fix in the field, and it is done and we are notified after. others, the customer is not as hands on - and it is a flight or warranty claim for something seemly simple.
q. The greatest challenge for us is more on the side of regaining reputation than cleaning oil spill
r. Finding the root cause
s. Increasing duty cycles on machines.
t. Education on true cost of leakage
u. To avoid unscrewing due to vibrations and high pressure without compromising the structural resistance of components
v. Proper installation of connectors, fittings, flanges, adaptors, pipe/hose runs....etc. The technology exists to reduce the occurrence of external leaks; however, often the decision on components d cost driven, not technology driven. Improperly tuned systems which experience shock contribute to external leaks
w. Keeping out external contamination
x. Training and materials
y. Customer always following specs products are designed for
z. Proper training of assembly and repair technicians to use torque wrenches, not just eyeball it.
aa. Durability of sealing components
bb. Preventing ingress of contaminating particles (which destroys seals)
cc. Increased cost of improved technology and entrenched industry standards.
dd. Understanding application's maintenance challenges and what can be done to prevent damage or misuse in application.
ee. personnel experience
ff. We mfr components. This is more of an integration issue.
gg. Convincing customers that torque values are important.
hh. Human assembly processes
ii. Access and torque
jj. There are too many connections in a small area when assembling equipment, so it is difficult to properly torque connectors

10. **What strategy has the best potential for eliminating external leakage?**
a. Precise determination of torque - for components producers the limit is to know the manifold material in the final application
b. Tell them, tell them, tell them, and tell them again. Presumably, with few exceptions, technology exists to minimize external leaks, but "quick & dirty", or "it only needs to survive the original warranty" design decisions likely do not take full advantage of technical solutions readily available.
c. Eliminating installation damage and eliminating the possibility of using the wrong part
d. Better maintenance training
e. Always get technical data sheet from applications to make sure all pressure, flow and oil type/temperature are communicated to our engineering for product specification
f. Not sure

g. Reminding customers to list torque specs in their assembly and service manuals and then enforcing the use of these documents.
h. Adding gland drains to know when primary seals are starting to fail. Eliminating NPT port connections.
i. Elimination of face seal o-rings and gaskets in favor of bore sealing o-ring joints.
j. Apply a failure mode analysis of some degree to each application, assist the customer in this process.
k. Proper documentation and training
l. Training and instruction
m. Operator independent assembly
n. Improved routing and reducing connections
o. Some way of doing push to connect that is serviceable

Definitions:

In fluid power systems, power is transmitted and controlled through a fluid (liquid or gas) under pressure within a circuit.

Connector: a device that connects tubes, hoses or pipes to each other or to other components

Conductor: tube or hose that conveys fluid between connectors

Crimped hose fitting: hose fitting attached to the hose by permanent deformation of one end of the hose fitting

Cylinder: actuator that provides linear motion

Hose: flexible conductor usually made of reinforced rubber or plastic

Leakage: fluid flow of a relatively small quantity that does no useful work and causes energy losses

Lip seal: seal that has a flexible sealing projection; fluid pressure acting on one side of the lip holds the other side in contact with a suitable surface against which to make the seal

Maximum working pressure: highest pressure at which a system or sub-system is intended to operate in steady-state operating conditions

O-ring: molded elastomeric seal that has a round cross section in the free state

Packing: sealing device consisting of one or more mating deformable elements usually subjected to adjustable axial compression to obtain effective radial sealing

Pressure: normal force per unit area exerted by a fluid against its confinement

Piping: any combination of connectors, couplings, tubes and/or hoses which allows fluid flow between components

Tube: rigid or semi-rigid conductor used to transmit fluid