Selecting tubing, fitting and filters

Introduction

In a hydraulic system, the fluid flows through a distribution system consisting of conductors and fittings, which used to connect system components and carry the fluid from the reservoir through operating components and back to the reservoir. They must be properly designed in order to function correctly for the total system.

Hydraulic systems use primarily four types of conductors:

1. Steel pipes
2. Steel tubing
3. Plastic tubing
4. Flexible hoses

Tube is measured by an exact outside diameter (OD) and wall thickness. Pipe is measured by a nominal outside diameter (also known as NPS or Nominal Pipe Size) and wall thickness. Tubes are stronger than pipe. Tubes perform better in applications that require durability and strength.

The choice of which type of conductor to use depends primarily on the system's operating pressures and flow rates. Conducting lines are available for handling working pressures up to 12,000 psi. In addition, the selection depends on environmental conditions such as the type of fluid, operating temperatures, vibration, and whether or not there is relative motion between connected components.

<u>Steel tubing</u> provides greater plumbing flexibility and neater appearance and requires fewer fittings than piping. However, piping is less expensive than steel tubing.

<u>Plastic tubing</u> is increased in industrial usage because it is not costly and circuits can be very easily hooked up due to its flexibility.

<u>Flexible hoses</u> are used primarily to connect components that experience relative motion. They are made from a large number of elastomeric (rubberlike) compounds and are capable of handling pressures up to 12,000 psi.

<u>Stainless steel conductors and fittings</u> are used if extremely corrosive environments are expected. However, they are very expensive and should be used only if necessary.

Copper conductors should not be used in hydraulic systems because the copper promotes the oxidation of petroleum oils.

Zinc, magnesium, and cadmium conductors should not be used either, because they are rapidly corroded by water glycol fluids.

Galvanized conductors should also be avoided because the galvanized surface has a tendency to flake off into the hydraulic fluid.

When using steel pipe or steel tubing, hydraulic fittings should be made of steel except for inlet, return, and drain lines, where malleable iron may be used.

Conductors and fittings must be designed with human safety in mind. They must be strong enough not only to withstand the steady-state system pressures but also the instantaneous pressure spikes resulting from hydraulic shock. Whenever control valves are closed suddenly, this quickly stops the flowing fluid, which possesses large amounts of kinetic energy. This produces shock waves whose pressure levels can be up to four times the steady-state system design values. The sudden stopping of actuators and the rapid acceleration of heavy loads also cause pressure spikes. These high-pressure pulses are taken into account by the application of an appropriate factor of safety.

Conductor sizing for flowrate requirements

$$v = v_{\text{avg}} = \frac{Q}{A}$$

EXAMPLE

A pipe handles a flow rate of 30 gpm. Find the minimum inside diameter that will provide an average fluid velocity not to exceed 20 ft/s.

Solution First, we convert the flow rate into units of ft^3/s.

$$Q(\text{ft}^3/\text{s}) = \frac{Q(\text{gpm})}{449} = \frac{30}{449} = 0.0668\ \text{ft}^3/\text{s}$$

Next, we solve for the minimum required pipe flow area:

$$A(\text{ft}^2) = \frac{Q(\text{ft}^3/\text{s})}{v(\text{ft/s})} = \frac{0.0668}{20} = 0.00334\ \text{ft}^2 = 0.481\ \text{in}^2$$

Finally, for a circular area we have

$$D(\text{in}) = \sqrt{\frac{4A(\text{in}^2)}{\pi}} = \sqrt{\frac{4 \times 0.481}{\pi}} = 0.783\ \text{in}$$

EXAMPLE

A pipe handles a flow rate of 0.002 m^3/s. Find the minimum inside diameter that will provide an average fluid velocity not to exceed 6.1 m/s.

Solution First, we solve for the minimum required pipe flow area:

$$A(\text{m}^2) = \frac{Q(\text{m}^3/\text{s})}{v(\text{m/s})} = \frac{0.002}{6.1} = 0.000328 \text{ m}^2$$

The minimum inside diameter can now be found.

$$D = \sqrt{\frac{4A(\text{m}^2)}{\pi}} = \sqrt{\frac{4 \times 0.000328}{\pi}} = 0.0204 \text{ m} = 20.4 \text{ mm}$$

Pressure rating of conductors

Tensile stress = force pulling on the pipe wall area / pipe wall area over which force acts

Substituting variables as shown in the next figure:

$$\sigma = \frac{F}{2tL} = \frac{pA}{2tL} = \frac{p(LD_i)}{2tL} = \frac{pD_i}{2t}$$

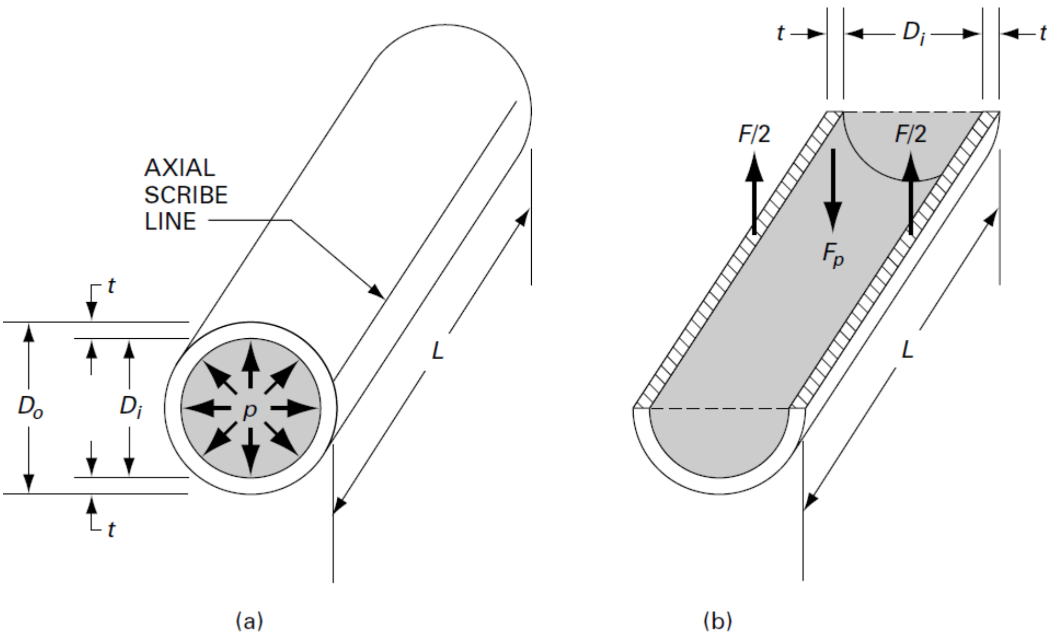


Fig: Forces in the wall of a pipe due to fluid pressure.

Burst Pressure and Working Pressure

$$\mathrm{BP} = \frac{2tS}{D_i}$$

$$\mathrm{WP} = \frac{\mathrm{BP}}{\mathrm{FS}}$$

Factors of safety based on corresponding operating pressures:

FS = 8 for pressures from 0 to 1000 psi

FS = 6 for pressures from 1000 to 2500 psi

FS = 4 for pressures above 2500 psi

For systems where severe pressure shocks are expected, a factor of safety of 10 is recommended.

EXAMPLE

A steel tubing has a 1.250-in outside diameter and a 1.060-in inside diameter. It is made of SAE 1010 dead soft cold-drawn steel having a tensile strength of 55,000 psi. What would be the safe working pressure for this tube assuming a factor of safety of 8?

Solution First, calculate the wall thickness of the tubing using $t = \frac{D_o - D_i}{2}$

$$t = \frac{1.250 - 1.060}{2} = 0.095 \text{ in}$$

Next, find the burst pressure for the tubing using $\mathrm{BP} = \frac{2tS}{D_i}$

$$\mathrm{BP} = \frac{(2)(0.095)(55{,}000)}{1.060} = 9860 \text{ psi}$$

Finally, using $\mathrm{WP} = \frac{\mathrm{BP}}{\mathrm{FS}}$ calculate the working pressure at which the tube can safely operate:

$$\mathrm{WP} = \frac{9860}{8} = 1{,}230 \text{ psi}$$

If we use of Thick-Walled Conductors

$$BP = \frac{2tS}{D_i + 1.2t}$$

$$WP = \frac{BP}{8} = \frac{tS}{4(D_i + 1.2t)} = \frac{0.095 \times 55{,}000}{4(1.060 + 1.2 \times 0.095)} = 1110 \text{ psi}$$

Conductor Sizing Based on Flow-Rate and Pressure Considerations

The proper size conductor for a given application is determined as follows:

1. Calculate the minimum acceptable inside diameter (Di) based on flow-rate requirements.
2. Select a standard-size conductor with an inside diameter equal to or greater than the value calculated based on flow-rate requirements.

   For Steel Pipe Sizes "https://www.archtoolbox.com/standard-pipe-dimensions/"
3. Determine the wall thickness (t) of the selected standard-size conductor using the following equation:

$$t = \frac{D_o - D_i}{2}$$

4. Based on the conductor material and system operating pressure (p), determine the tensile strength (S) and factor of safety (FS).
5. Calculate the burst pressure (BP) and working pressure (WP) using.
6. If the calculated working pressure is greater than the operating fluid pressure, the selected conductor is acceptable. If not, a different standard-size conductor with a greater wall thickness must be selected and evaluated. An acceptable conductor is one that meets the flow-rate requirement and has a working pressure equal to or greater than the system operating fluid pressure.

BP = burst pressure (psi, MPa).

Di = conductor inside diameter (in, m).

Do = conductor outside diameter (in, m).

FS = factor of safety (dimensionless).

p = system operating fluid pressure (psi, MPa).

S = tensile strength of conductor material (psi, MPa).

t = conductor wall thickness (in, m).

WP = working pressure (psi, MPa).

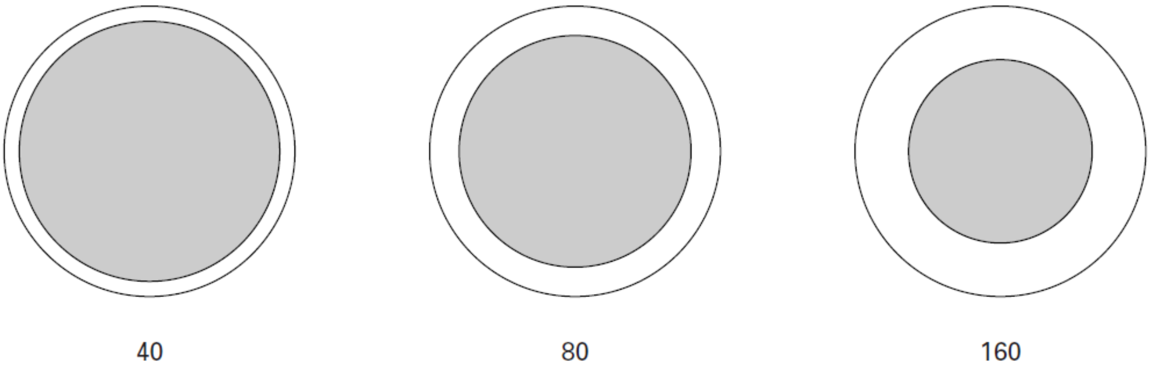
S = tensile stress (psi, MPa).

STEEL PIPES

Size Designation

Table: Common pipe sizes.

NOMINAL PIPE SIZE	PIPE OUTSIDE DIAMETER	PIPE INSIDE DIAMETER		
		SCHEDULE 40	SCHEDULE 80	SCHEDULE 160
1/8	0.405	0.269	0.215	–
1/4	0.540	0.364	0.302	–
3/8	0.675	0.493	0.423	–
1/2	0.840	0.622	0.546	0.466
3/4	1.050	0.824	0.742	0.614
1	1.315	1.049	0.957	0.815
1-1/4	1.660	1.380	1.278	1.160
1-1/2	1.900	1.610	1.500	1.338
2	2.375	2.067	1.939	1.689



Thread Design

Pipes have only tapered threads whereas tube and hose fittings have straight threads and also tapered threads as required to connect to hydraulic components. As shown in Figure, pipe joints are sealed by an interference fit between the male and female threads as the pipes are tightened. This causes one of the major problems in using pipe. When a joint is taken apart, the pipe must be tightened further to reseal. This frequently requires replacing some of the pipe with slightly longer sections, although this problem has been overcome somewhat by using Teflon tape to reseal the pipe joints.

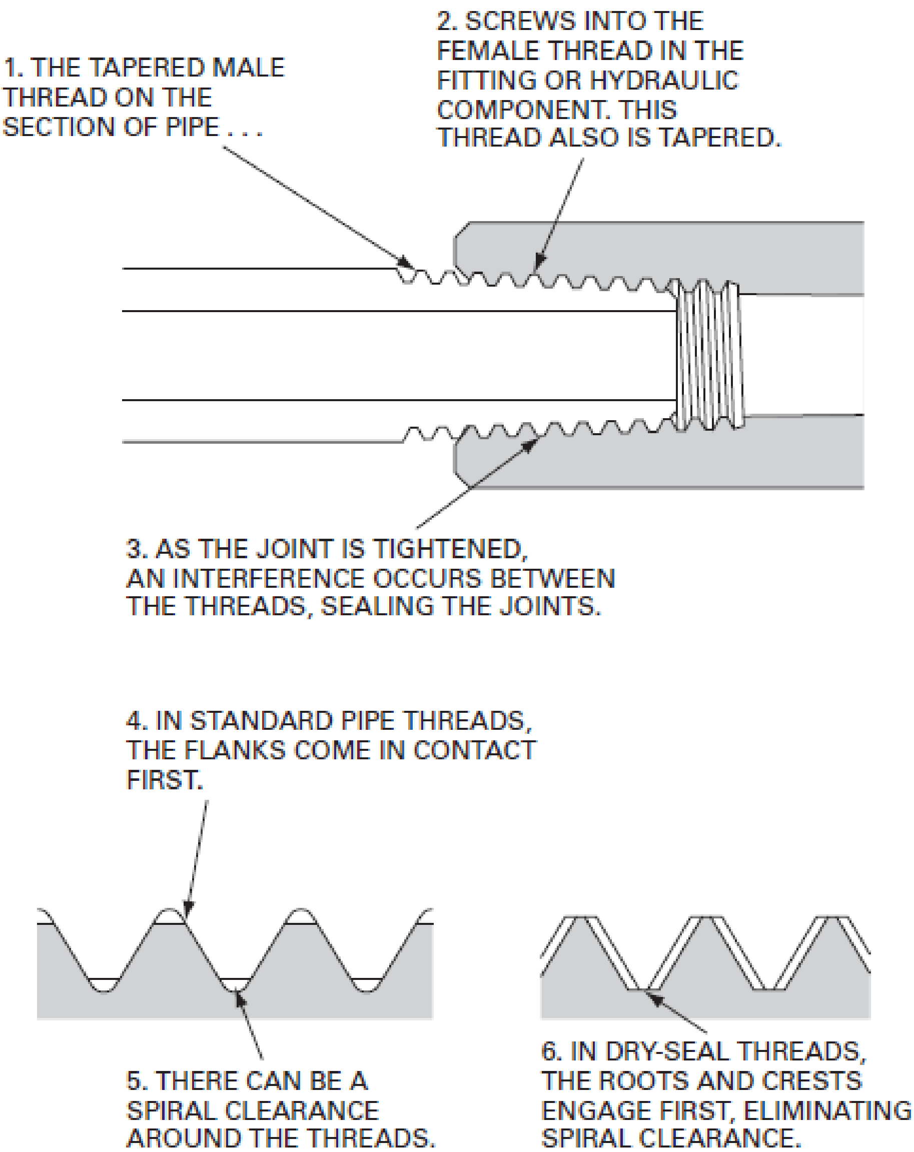


Fig. Hydraulic pipe threads are the dry-seal tapered type.

(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)

Hydraulic pipe threads are the dry-seal type. They differ from standard pipe threads because they engage the roots and crests before the flanks. In this way, spiral clearance is avoided. Pipes can have only male threads, and they cannot be bent around obstacles. There are, of course, various required types of fittings to make end connections and change direction, as shown in Figure. The large number of required pipe fittings in a hydraulic circuit presents many opportunities for leakage, especially as pressure increases. Threaded-type fittings are used in sizes up to 1 in diameter.

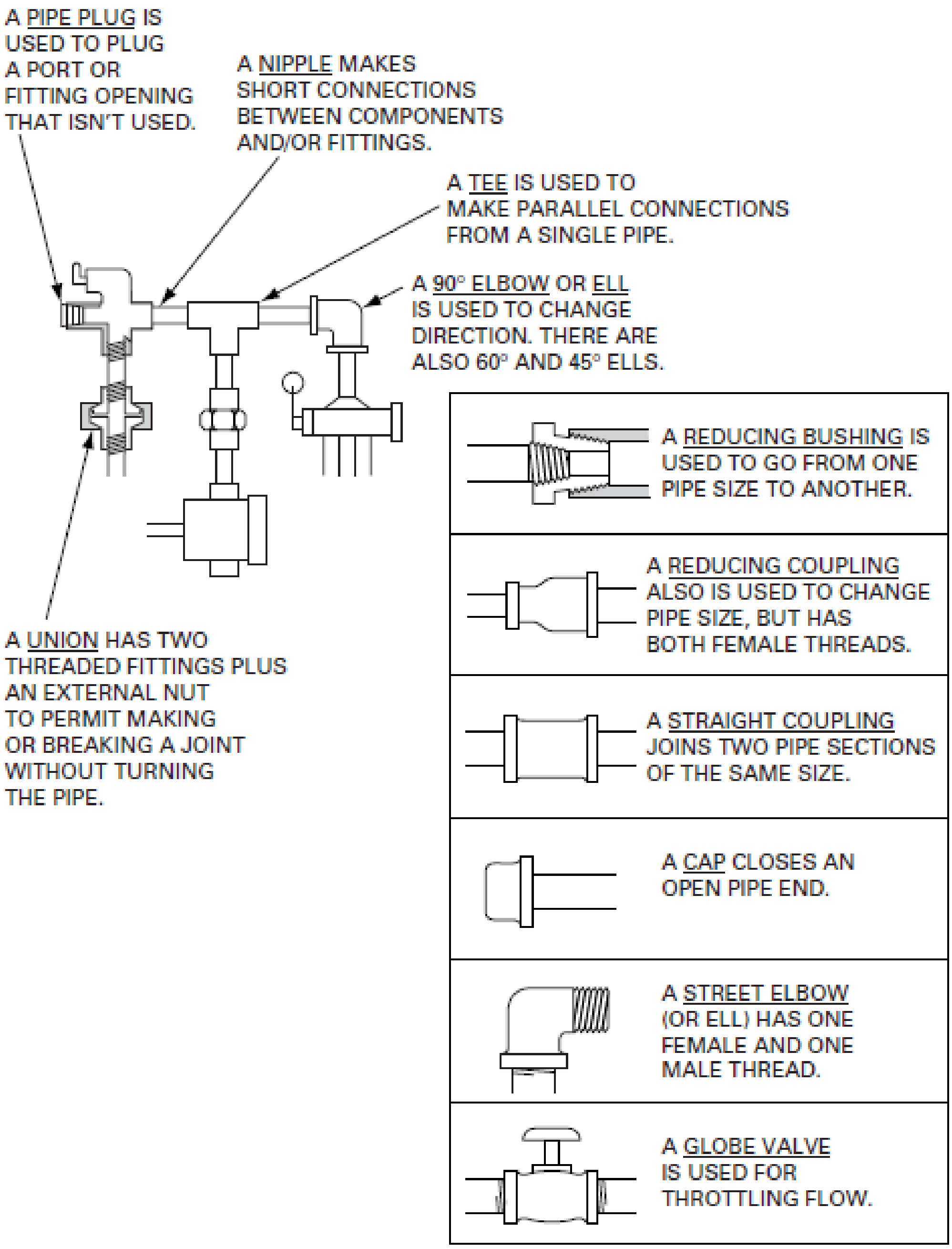
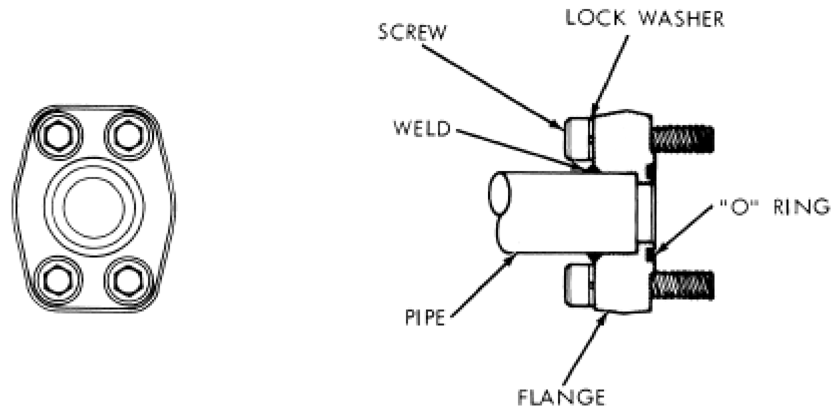
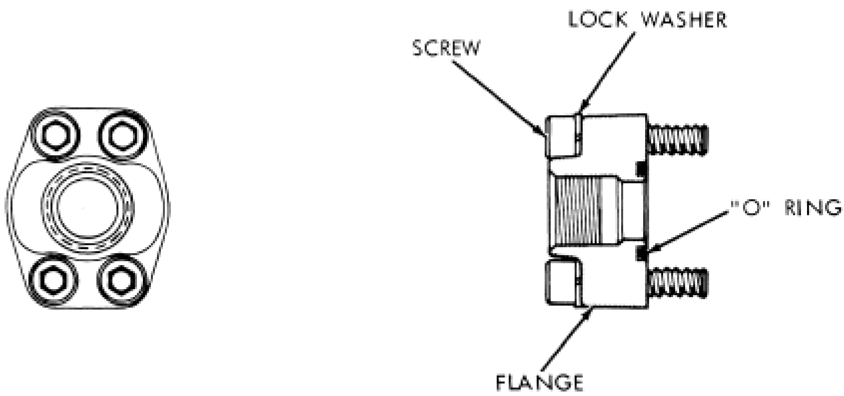


Fig. Fittings make the connections between pipes and components.
(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)

Where larger pipes are required, flanges are welded to the pipe, as illustrated in Figure. As shown, flat gaskets or O-rings are used to seal the flanged fittings.



SOCKET WELD PIPE CONNECTIONS
STRAIGHT TYPE



THREADED PIPE CONNECTIONS
STRAIGHT TYPE

Fig.Flanged connections for large pipes.

(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)

It is not a good idea to make connections to a pump with pipe or steel tubing. The natural vibration of the pump can, over time, damage the connection. Using pipe for connections also amplifies the pump noise. Using hose to connect to a pump at the pressure discharge port can help dampen the oil’s pulsations particularly with piston pumps. All connections to pumps should be made using flexible hose.

STEEL TUBING

Size Designation

Seamless steel tubing is the most widely used type of conductor for hydraulic systems as it provides significant advantages over pipes. The tubing can be bent into almost any shape, thereby reducing the number of required fittings. Tubing is easier to handle and can be reused without any sealing problems. For low-volume systems, tubing can handle the pressure and flow requirements with less bulk and weight. However, tubing and its fittings are more expensive. A tubing size designation always refers to the outside diameter.

Table: Common tube sizes.

TUBE OD (in)	WALL THICKNESS (in)	TUBE ID (in)	TUBE OD (in)	WALL THICKNESS (in)	TUBE ID (in)	TUBE OD (in)	WALL THICKNESS (in)	TUBE ID (in)
1/8	0.035	0.055	1/2	0.035	0.430	7/8	0.049	0.777
				0.049	0.402		0.065	0.745
3/16	0.035	0.118		0.065	0.370		0.109	0.657
				0.095	0.310			
1/4	0.035	0.180				1	0.049	0.902
	0.049	0.152	5/8	0.035	0.555		0.065	0.870
	0.065	0.120		0.049	0.527		0.120	0.760
				0.065	0.495			
5/16	0.035	0.243		0.095	0.435	1-1/4	0.065	1.120
	0.049	0.215					0.095	1.060
	0.065	0.183	3/4	0.049	0.652		0.120	1.010
				0.065	0.620			
3/8	0.035	0.305		0.109	0.532	1-1/2	0.065	1.370
	0.049	0.277					0.095	1.310
	0.065	0.245						

EXAMPLE

Select the proper size steel tube for a flow rate of 30 gpm and an operating pressure of 1000 psi. The maximum recommended velocity is 20 ft/s, and the tube material is SAE 1010 dead soft cold-drawn steel having a tensile strength of 55,000 psi.

Solution The minimum inside diameter based on the fluid velocity limitation of 20 ft/s is the same as that found in Example 10-1 (0.783 in).

From table , the two smallest acceptable tube sizes based on flow-rate requirements are

1-in OD, 0.049-in wall thickness, 0.902-in ID

1-in OD, 0.065-in wall thickness, 0.870-in ID

Let's check the 0.049-in wall thickness tube first since it provides the smaller velocity:

$$BP = \frac{(2)(0.049)(55{,}000)}{0.902} = 5980 \text{ psi}$$

$$WP = \frac{5980}{8} = 748 \text{ psi}$$

This working pressure is not adequate, so let's next examine the 0.065-in wall thickness tube:

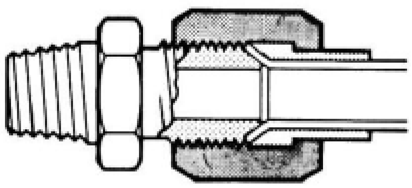
$$BP = \frac{(2)(0.065)(55{,}000)}{0.870} = 8220 \text{ psi}$$

$$WP = \frac{8220}{8} = 1030 \text{ psi}$$

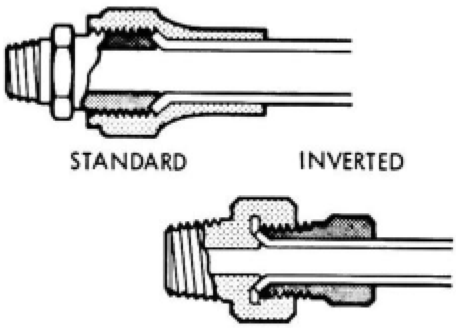
$$D_i/t = 0.870 \text{ in}/0.065 \text{ in} = 12.9$$

Tube Fittings

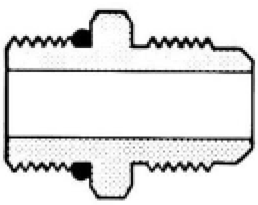
Tubing is not sealed by threads but by special kinds of fittings, as illustrated in the next figure. Some of these fittings are known as compression fittings. They seal by metal-to metal contact and may be either the flared or flareless type. Other fittings may use O-rings for sealing purposes. The 37° flare fitting is the most widely used fitting for tubing that can be flared. The fittings shown in Figure (a) and (b) seal by squeezing the flared end of the tube against a seal as the compression nut is tightened. A sleeve inside the nut supports the tube to dampen vibrations. The standard 45° flare fitting is used for very high pressures. It is also made in an inverted design with male



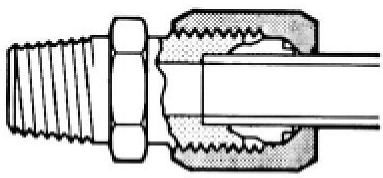
(a) 37° FLARE FITTING



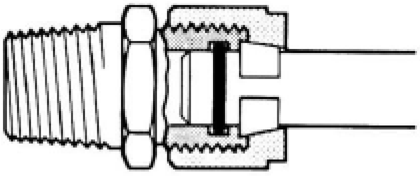
(b) 45° FLARE FITTING



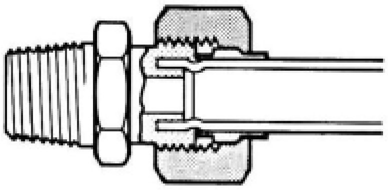
(c) STRAIGHT THREAD "O" RING CONNECTOR



(d) FERRULE COMPRESSION FITTING



(e) "O" RING COMPRESSION FITTING



(f) SLEEVE COMPRESSION FITTING

Fig. Threaded fittings and connectors used with tubing.

(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)

Two assembly precautions when using flared fittings are:

1. The compression nut needs to be placed on the tubing before flaring the tube.
2. These fittings should not be over tightened.Too great a torque damages the sealing surface and thus may cause leaks.

PLASTIC TUBING

Plastic tubing has gained rapid acceptance in the fluid power industry because it is relatively inexpensive. Also, it can be readily bent to fit around obstacles, it is easy to handle, and it can be stored on reels. Another advantage is that it can be color-coded to represent different parts of the circuit because it is available in many colors. Since plastic tubing is flexible, it is less susceptible to vibration damage than steel tubing.

Fittings for plastic tubing are almost identical to those designed for steel tubing. In fact many steel tube fittings can be used on plastic tubing, as is the case for the Swagelok fitting of next Figures.

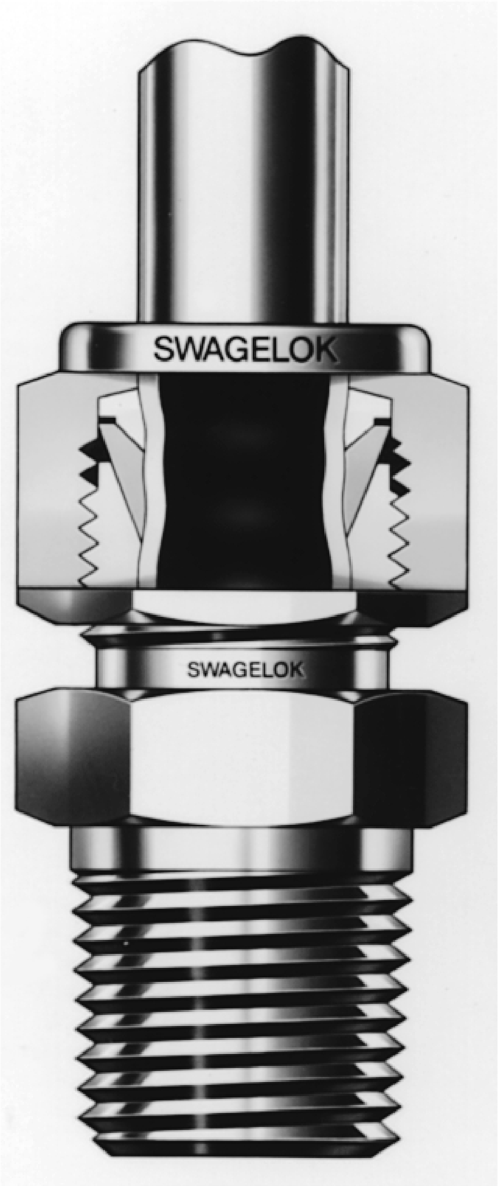


Fig. Swagelok tube fitting.(Courtesy of Swagelok Co., Solon, Ohio.)


Fig. The 45° flare fitting. (Courtesy of Gould, Inc.,

Valve and Fittings Division, Chicago, Illinois.)

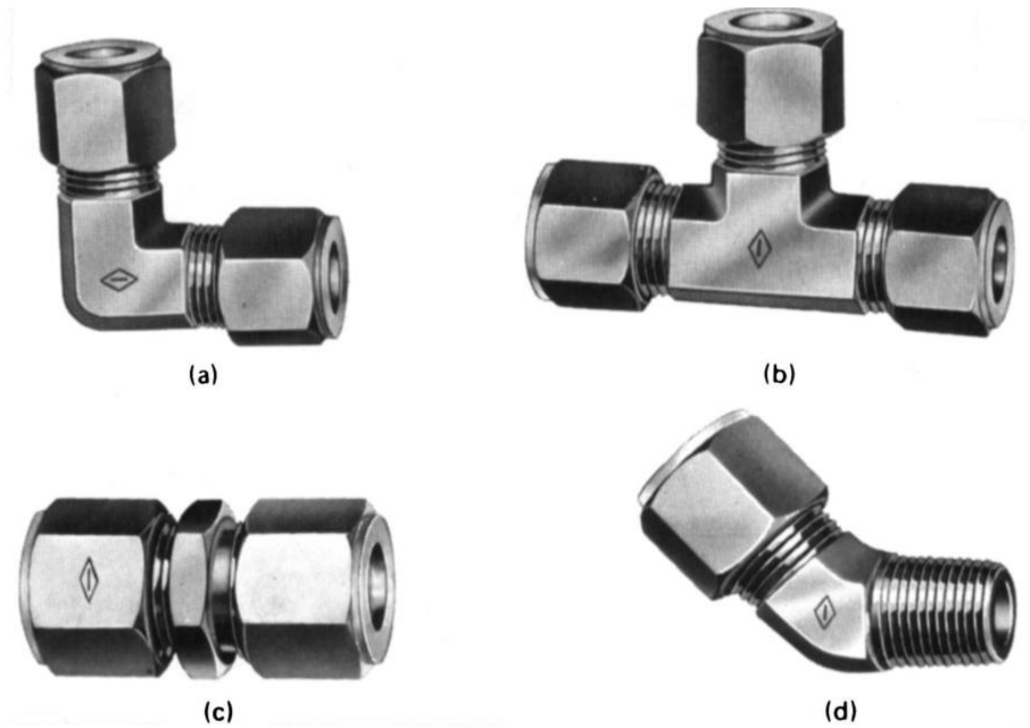


Fig. Various steel tube fittings. (a) Union elbow, (b) union tee,(c) union, (d) 45° male elbow. (Courtesy of Gould, Inc., Valve and FittingsDivision, Chicago, Illinois.)

In another design, a sleeve is placed inside the tubing to give it resistance to crushing at the area of compression, as illustrated in Figure. In this particular design (called the Poly-Flo Flareless Tube Fitting), the sleeve is fabricated onto the fitting so it cannot be accidentally left off. Plastic tubing is used universally in pneumatic systems because air pressures are low, normally less than 100 psi. Of course, plastic tubing is compatible with most hydraulic fluids and hence is used in low-pressure hydraulic applications. Materials for plastic tubing include polyethylene, polyvinyl chloride, polypropylene, and nylon. Each material has special properties that are desirable for specific applications. Manufacturers' catalogs should be consulted to determine which material should be used for a particular application.

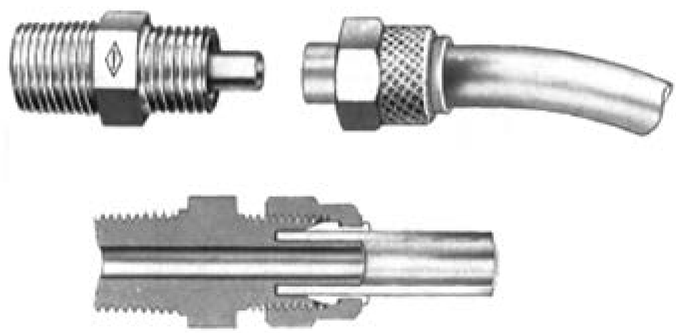


Figure . Poly-Flo Flareless Plastic Tube Fitting. *(Courtesy of Gould, Inc., Valve and Fittings Division, Chicago, Illinois.)*

FLEXIBLE HOSES

Design and Size Designation

The fourth major type of hydraulic conductor is the flexible hose, which is used when hydraulic components such as actuators are subjected to movement. Examples of this are found in portable power units, mobile equipment, and hydraulically powered machine tools. Hose is fabricated in layers of elastomer (synthetic rubber) and braided fabric or braided wire, which permits operation at higher pressures.

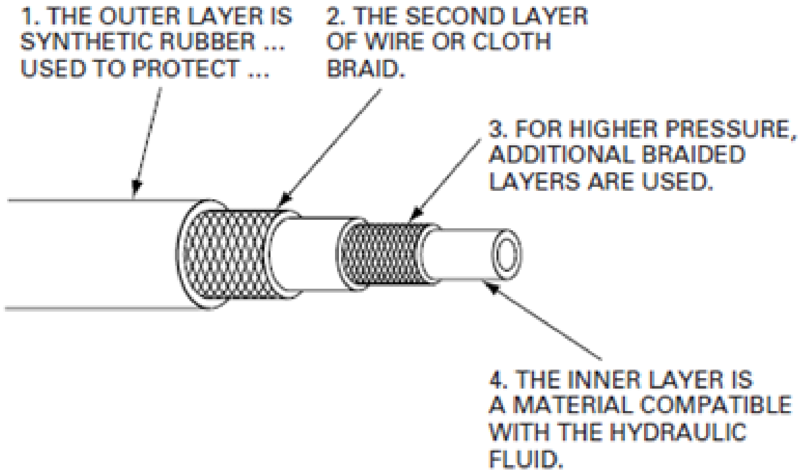


Figure . Flexible hose is constructed in layers. *(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)*

Table: Typical hose sizes

HOSE SIZE	OD TUBE SIZE (in)	SINGLE-WIRE BRAID			DOUBLE-WIRE BRAID		
		HOSE ID (in)	HOSE OD (in)	MINIMUM BEND RADIUS (in)	HOSE ID (in)	HOSE OD (in)	MINIMUM BEND RADIUS (in)
4	1/4	3/16	33/64	1-15/16	1/4	11/16	4
6	3/8	5/16	43/64	2-3/4	3/8	27/32	5
8	1/2	13/32	49/64	4-5/8	1/2	31/32	7
12	3/4	5/8	1-5/64	6-9/16	3/4	1-1/4	9-1/2
16	1	7/8	1-15/64	7-3/8	1	1-9/16	11
20	1-1/4	1-1/8	1-1/2	9	1-1/4	2	16

Five different flexible hose designs constructions are described as follows:

a. FC 194: Elastomer inner tube, single-wire braid reinforcement, and elastomer cover. Working pressures vary from 375 to 2750 psi depending on the size.

b. FC 195: Elastomer inner tube, double-wire braid reinforcement, and elastomer cover. Working pressures vary from 1125 to 5000 psi depending on the size.

c. FC 300: Elastomer inner tube, polyester inner braid, single-wire braid reinforcement, and polyester braid cover. Working pressures vary from 350 to3000 psi depending on the size.

d. 1525: Elastomer inner tube, textile braid reinforcement, oil and mild resistant, and textile braid cover. Working pressure is 250 psi for all sizes.

e. 2791: Elastomer inner tube, partial textile braid, four heavy spiral wire reinforcements, and elastomer cover. Working pressure is 2500 psi for all sizes.

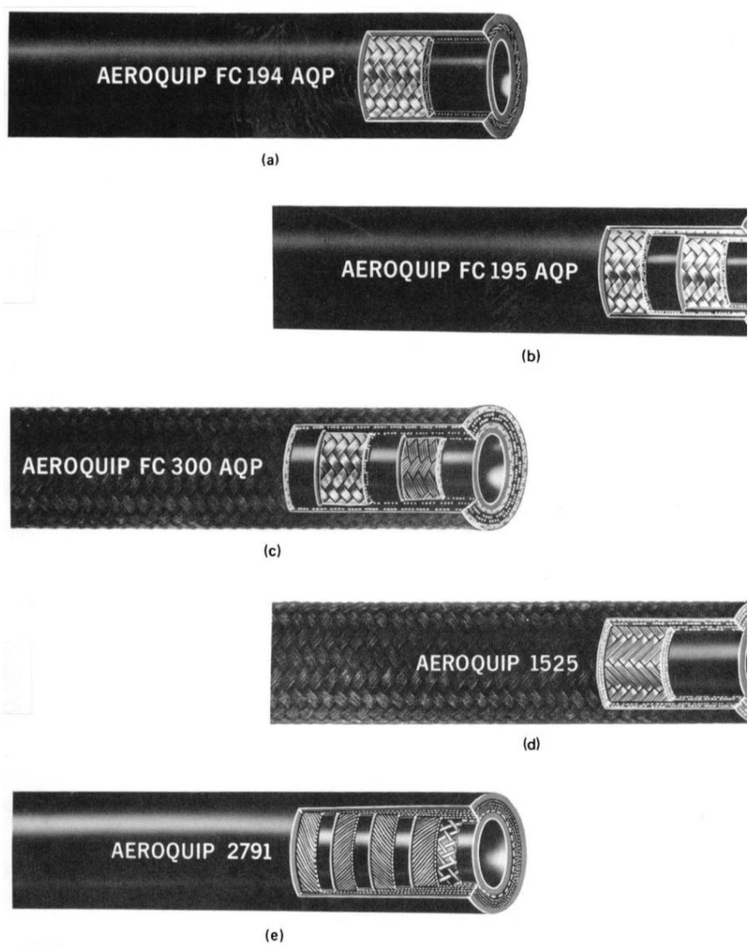


Fig. Various flexible hose designs. (a) FC 194: single-wire braid; (b) FC 195: double wire braid; (c) FC 300: single-wire braid, polyester inner braid; (d) 1525: single-textile braid; (e) 2791: four heavy spiral wires, partial textile braid.

(Courtesy of Aeroquip Corp., Jackson, Michigan.)

Hose Fittings

Hose assemblies of virtually any length and with various end fittings are available from manufacturers. See Figure for examples of hoses with the following permanently attached end fittings: (a) straight fitting, (b) 45° elbow fitting, and (c) 90° elbow fitting.

The elbow-type fittings allow access to hard-to-get-at connections. They also permit better flexing and improve the appearance of the system.

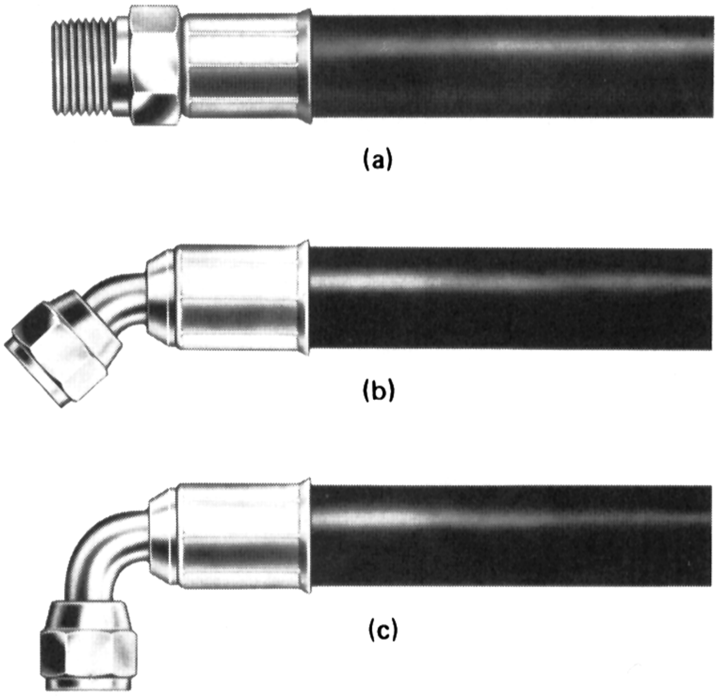


Fig. Flexible hoses with permanently attached end fittings. (a) Straight fitting,
(b) 45° elbow fitting, (c) 90° elbow fitting.
(Courtesy of Aeroquip Corp., Jackson,Michigan.)

Figure shows the three corresponding reusable-type end fittings. These types can be detached from a damaged hose and reused on a replacement hose. Hose Routing and Installation Care should be taken in changing fluid in hoses since the hose and fluid materials must be compatible. Flexible hose should be installed so there is no kinking during operation of the system. There should always be some slack to relieve any strainand allow for the absorption of pressure surges. It is poor practice to twist the hose and use long loops in the plumbing operation. It may be necessary to use clamps to prevent chafing or tangling of the hose with moving parts. If the hose is subject to rubbing, it should be encased in a protective sleeve.

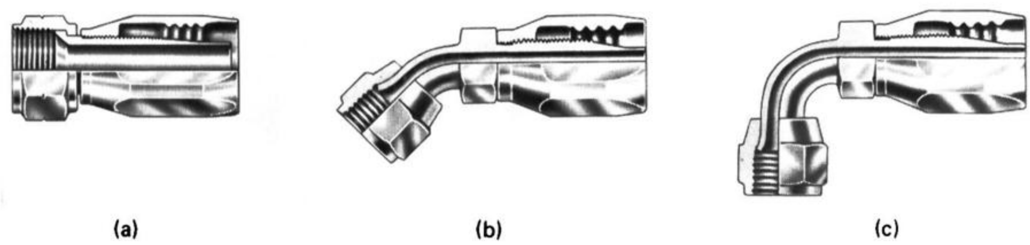


Fig. Flexible hose reusable-type end fittings. (a) Straight fitting, (b) elbow fitting, (c) 90° elbow fitting.(Courtesy of Aeroquip Corp., Jackson, Michigan.)

Next figure gives basic information on hose routing and installation procedures.

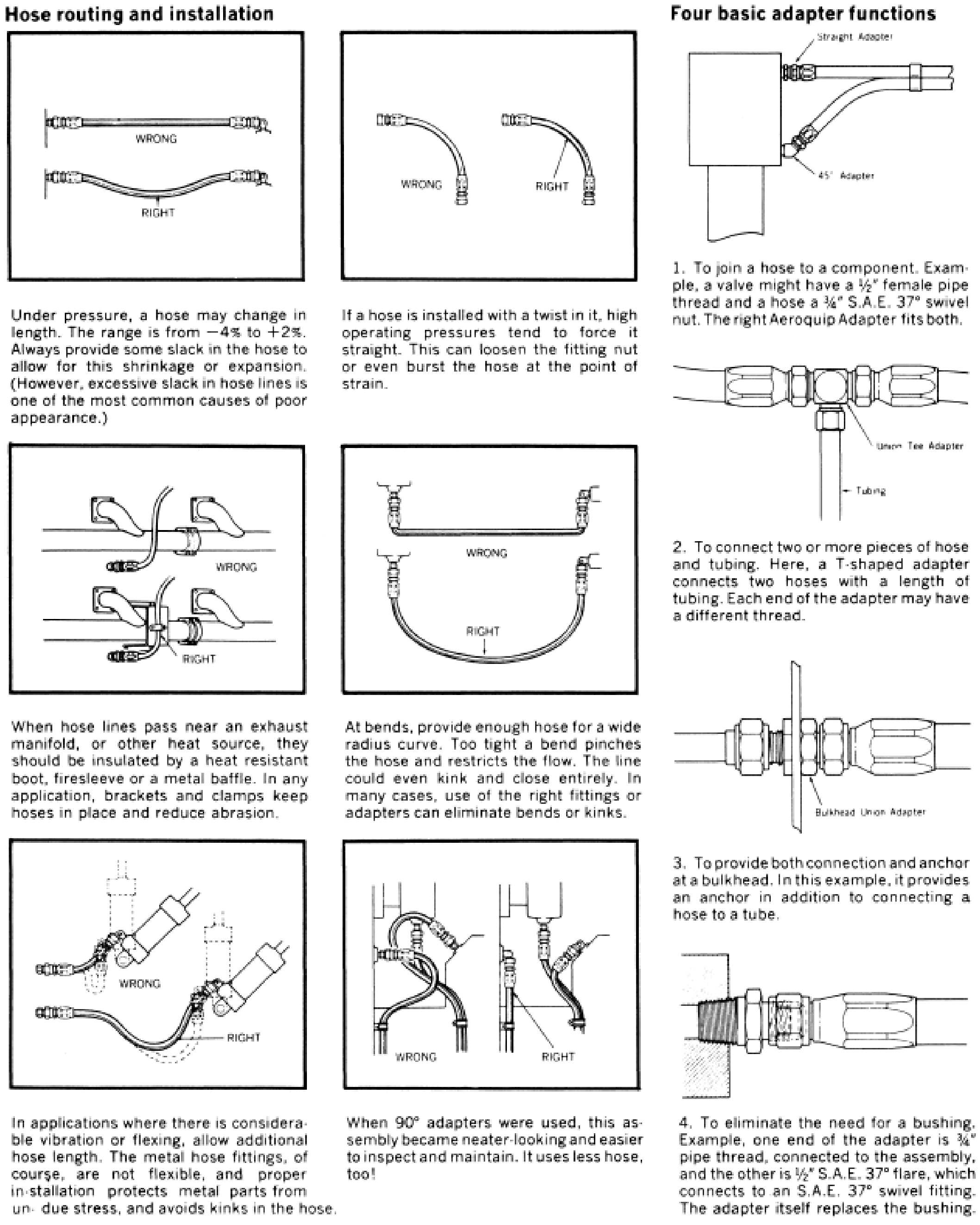


Fig. Hose routing and installation information.

METRIC STEEL TUBING

In this section we examine common metric tube sizes and show how to select the proper size tube based on flow-rate requirements and strength considerations. Table shows the common tube sizes used in fluid power systems. Note that the smallest OD size is 4 mm (0.158 in), whereas the largest OD size is 42 mm.

Table: Common metric tube sizes.

Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)	Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)	Tube OD (mm)	Wall Thickness (mm)	Tube ID (mm)
4	0.5	3	14	2.0	10	25	3.0	19
6	1.0	4	15	1.5	12	25	4.0	17
6	1.5	3	15	2.0	11	28	2.0	24
8	1.0	6	16	2.0	12	28	2.5	23
8	1.5	5	16	3.0	10	30	3.0	24
8	2.0	4	18	1.5	15	30	4.0	22
10	1.0	8	20	2.0	16	35	2.0	31
10	1.5	7	20	2.5	15	35	3.0	29
10	2.0	6	20	3.0	14	38	4.0	30
12	1.0	10	22	1.0	20	38	5.0	28
12	1.5	9	22	1.5	19	42	2.0	38
12	2.0	8	22	2.0	18	42	3.0	36

These values compare to 0.125 in and 1.500 in, respectively, for common English units tube sizes. Factors of safety based on corresponding operating pressures become

FS = 8 for pressures from 0 to 1000 psi 10 to 7 MPa or 0 to 70 bars

FS = 6 for pressures from 1000 to 2500 psi 17 to 17.5 MPa or 70 to 175 bars

FS = 4 for pressures above 2500 psi 17.5 MPa or 175 bars

The corresponding tensile strengths for SAE 1010 dead soft cold-drawn steeland AISI 4130 steel are

SAE 1010	55,000 psi or 379 MPa
AISI 4130	75,000 psi or 517 MPa

EXAMPLE

Select the proper metric size steel tube for a flow rate of 0.00190 m^3/s and an operating pressure of 70 bars. The maximum recommended velocity is 6.1 m/s and the tube material is SAE 1010 dead soft cold-drawn steel having a tensile strength of 379 MPa.

Solution The minimum inside diameter based on the fluid velocity limitation of 6.1 m/s is found using Eq. (3-38):

$$Q(\text{m}^3/\text{s}) = A(\text{m}^2) \times v(\text{m/s})$$

Solving for A, we have

$$A = Q/v$$

Since $A = \frac{\pi}{4}(\text{ID})^2$, we have the final resulting equation:

$$\text{ID} = \sqrt{\frac{4Q}{\pi v}}$$

Substituting values we have

$$\text{ID} = \sqrt{\frac{(4)(0.00190)}{\pi(6.1)}} = 0.0199\text{ m} = 19.9\text{ mm}$$

From Figure 10-20, the smallest acceptable OD tube size is

22-mm OD, 1.0-mm wall thickness, 20-mm ID

From Eq. (10-3) we obtain the burst pressure.

$$\text{BP} = \frac{2tS}{D_i} = \frac{(2)(0.001\text{m})(379\text{ MN/m}^2)}{0.020\text{ m}} = 37.9\text{ MN/m}^2 = 37.9\text{ MPa}$$

Then, we calculate the working pressure using Eq. (10-4).

$$\text{WP} = \frac{\text{BP}}{\text{FS}} = \frac{37.9\text{ MPa}}{8} = 4.74\text{ MPa} = 47.4\text{ bars}$$

This pressure is not adequate (less than operating pressure of 70 bars), so let's examine the next larger size OD tube having the necessary ID.

28-mm OD, 2.0-mm wall thickness, 24-mm ID

$$\text{BP} = \frac{(2)(0.002)(379)}{0.024} = 63.2\text{ MPa}$$

$$\text{WP} = \frac{63.2}{8} = 7.90\text{ MPa} = 79.0\text{ bars}$$

$$D_i/t = 24\text{ mm}/2\text{ mm} = 12 > 10$$

This result is acceptable.

Filters and Strainers

Modern hydraulic systems must be dependable and provide high accuracy. This requires highly precision-machined components. The worst enemy of a precision made hydraulic component is contamination of the fluid. Essentially, contamination is any foreign material in the fluid that results in detrimental operation of any component of the system. Contamination may be in the form of a liquid, gas, or solid and can be caused by any of the following:

1. Built into system during component maintenance and assembly. Contaminants here include metal chips, bits of pipe threads, tubing burrs, pipe dope, shreds of plastic tape, bits of seal material, welding beads, bits of hose, and dirt.
2. Generated within the system during operation. During the operation of a hydraulic system, many sources of contamination exist. They include moisture due to water condensation inside the reservoir, entrained gases, scale caused by rust, bits of worn seal materials, particles of metal due to wear, and sludges and varnishes due to oxidation of the oil.
3. Introduced into the system from an external environment. The main source of contamination here is due to the use of dirty maintenance equipment such as funnels, rags, and tools. Disassembled components should be washed using clean hydraulic fluid before assembly. Any oil added to the system should be free of contaminants and poured from clean containers.

Filters

There are three basic types of filtering methods used in hydraulic systems: mechanical, absorbent and adsorbent.

1. Mechanical: This type normally contains a metal or cloth screen or a series of metal disks separated by thin spacers. Mechanical-type filters are capable of removing only relatively coarse particles from the fluid.
2. Absorbent: These filters are porous and permeable materials such as paper, wood pulp, diatomaceous earth, cloth, cellulose, and asbestos. Paper filters are normally impregnated with a resin to provide added strength.
3. Adsorbent: Adsorption is a surface phenomenon and refers to the tendency of particles to cling to the surface of the filter. Thus, the capacity of such a filter depends on the amount of surface area available. Adsorbent used materials include activated clay and chemically treated paper. Charcoal and Fuller’s earth should not be used because they remove some of the essential additives from the hydraulic fluid.

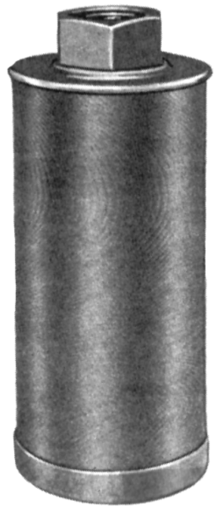
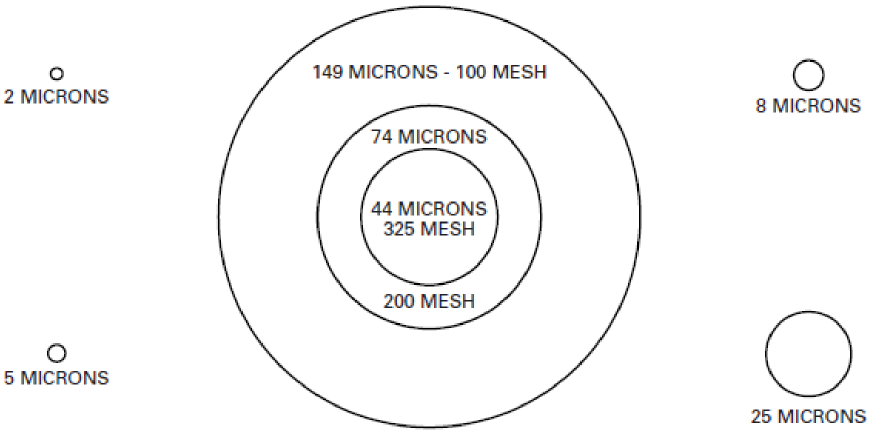


Fig. Inlet strainer.(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)



RELATIVE SIZES

LOWER LIMIT OF VISIBILITY (NAKED EYE)	40 MICRONS
WHITE BLOOD CELLS	25 MICRONS
RED BLOOD CELLS	8 MICRONS
BACTERIA (COCCI)	2 MICRONS

LINEAR EQUIVALENTS

1 INCH	25.4 MILLIMETERS	25,400 MICRONS
1 MILLIMETER	.0394 INCHES	1,000 MICRONS
1 MICRON	1/25,400 OF AN INCH	.001 MILLIMETERS
1 MICRON	3.94×10^{-5} INCHES	.000039 INCHES

SCREEN SIZES

MESHES PER LINEAR INCH	U.S. SIEVE NO.	OPENING IN INCHES	OPENING IN MICRONS
52.36	50	.0117	297
72.45	70	.0083	210
101.01	100	.0059	149
142.86	140	.0041	105
200.00	200	.0029	74
270.26	270	.0021	53
323.00	325	.0017	44

Fig. Relative and absolute sizes of micronic particles.

Some filters are designed to be installed in the pressure line and normally are used in systems where high-pressure components such as valves are more dirt sensitive than the pump. Pressure line filters are accordingly designed to sustain system operating pressures. Return line filters are used in systems that do not have a very large reservoir to permit contaminants to settle to the bottom. A return line filter is needed in systems containing close-tolerance, high-performance pumps, because inlet line filters, which have limited pressure drop allowance, cannot filter out extremely small particles in the 1- to 5-μm range.

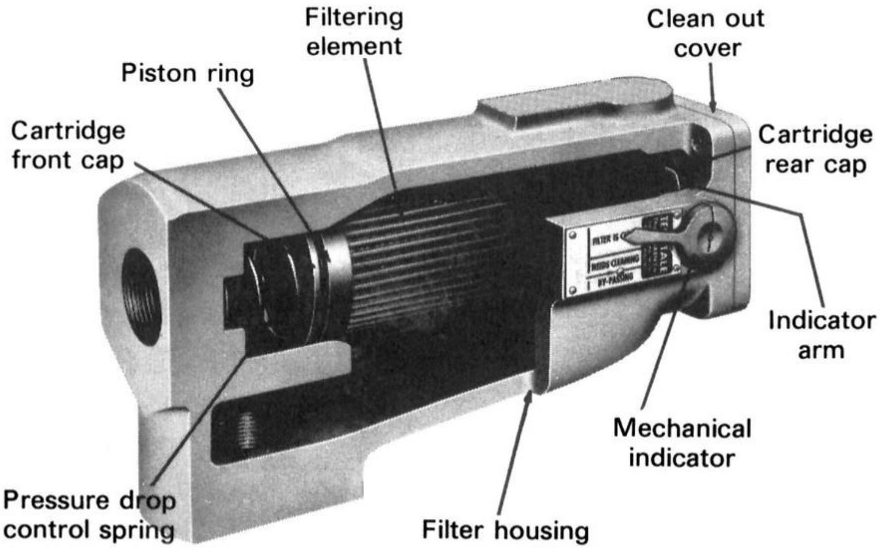


Fig. Cutaway view of a Tell-Tale filter.

The considerations for using these four filter locations are described as follows:

1. Single location for proportional flow filters.
2. Three locations for full flow filters.

In general, there is no best single place to put a filter. The basic rule of thumb is the following: Consider where the dirt enters the system, and put the filter/filters where they do the most good. Good hydraulic systems have multiple filters. There should always be a filter in the pump inlet line and a high-pressure filter in the pump discharge line. Placing the pump discharge filter between the pump and the pressure relief valve can provide very good filtration because oil is flowing through the filter even when the working part of the circuit is inactive and the pump discharge is going directly to the reservoir.

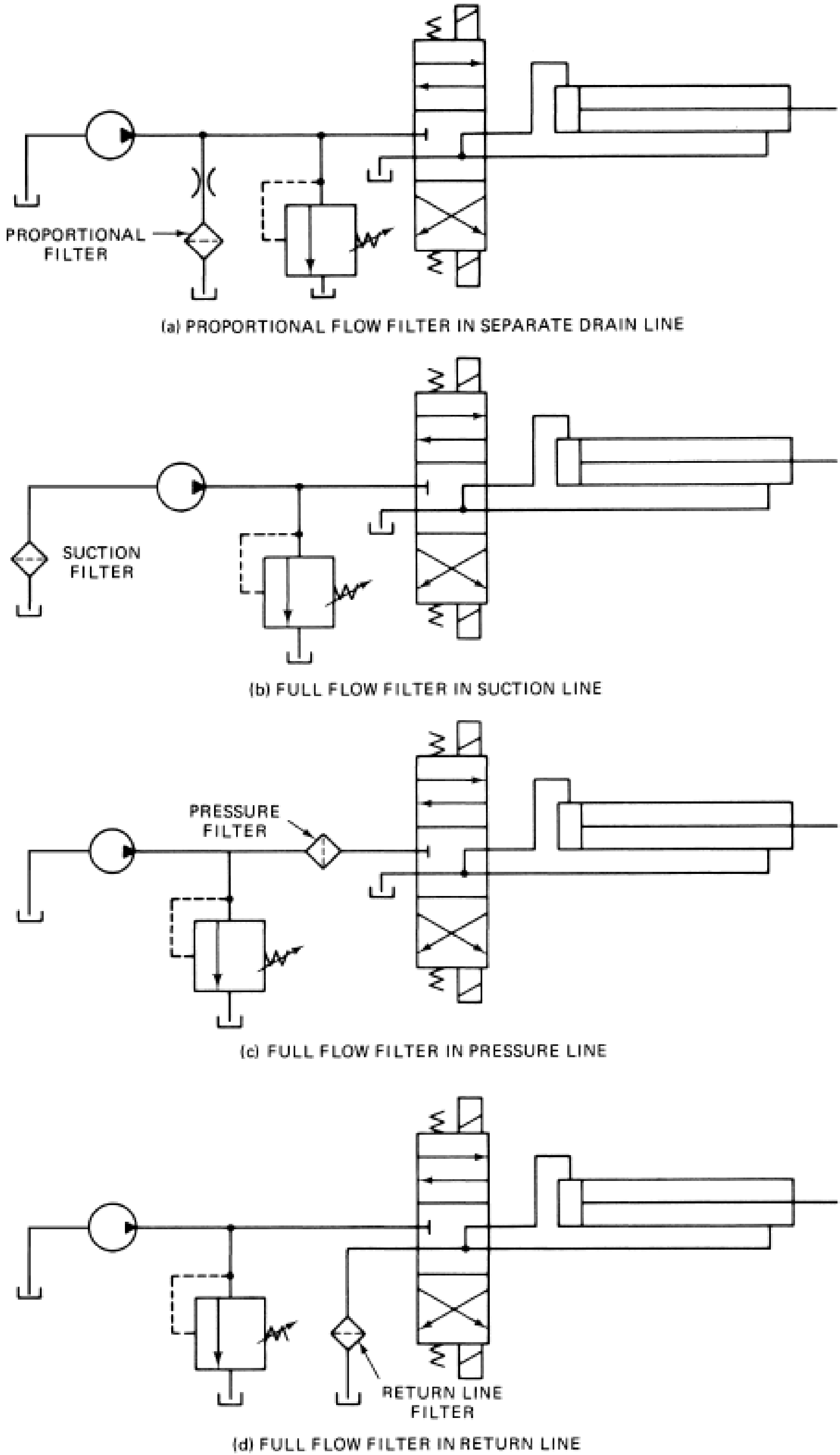


Fig. Four common circuit locations for filters.

Flow Capacity of filters

One of the parameters, involved in the selection of a filter for a given application, is the maximum flow rate that a filter is designed to handle. This parameter, which is called the flow capacity, is specified by filter manufacturers.

EXAMPLE

Determine the minimum flow capacity of the return line filter of Figure (d). The pump flow rate is 20 gpm and the cylinder piston and rod diameters are 5 in and 3 in, respectively.

Solution Note that during the cylinder retraction stroke, the flow rate through the return line filter exceeds the pump flow rate. Thus, the flow capacity of the filter must equal or exceed the flow rate it receives during the cylinder retraction stroke. The cylinder retraction speed is found first:

$$v_{ret} = \frac{Q_{pump}}{A_p - A_R}$$

where

$$Q_{pump} = 20\,\frac{\text{gal}}{\text{min}} \times \frac{231\ \text{in}^3}{1\ \text{gal}} = 4620\ \text{in}^3/\text{min}$$

$$A_P = \frac{\pi}{4}(5\ \text{in})^2 = 19.63\ \text{in}^2 \text{ and } A_R = \frac{\pi}{4}(3\ \text{in})^2 = 7.07\ \text{in}^2$$

Thus, we have $v_{ret} = \dfrac{4620\ \text{in}^3/\text{min}}{19.63\ \text{in}^2 - 7.07\ \text{in}^2} = 368\ \text{in/min}$

The flow rate through the filter during the cylinder retraction stroke can now be found.

$$Q_{filter} = A_P v_{ret} = 19.63\ \text{in}^2 \times 368\,\frac{\text{in}}{\text{min}} \times \frac{1\ \text{gal}}{231\ \text{in}^3} = 31.3\ \text{gpm}$$

Thus, the filter must have a flow capacity of at least 31.3 gpm rather than the pump flow-rate value of 20 gpm.

Fluid cleanliness levels

The basis for controlling the particle contamination of a hydraulic fluid is to measure the fluid's cleanliness level. This means counting the particles per unit volume for specific particle sizes and comparing the results to a required cleanliness level. This allows for the selection of the proper filtration system for a given hydraulic application. Sensitive optical instruments are used to count the number of particles in the specified size ranges. The result of the counting is a report of the number of particles greater than a certain size found per milliliter of fluid.

Next table provides a table showing cleanliness level standard accepted by the ISO (International Standards Organization).

Table: ISO code numbers for fluid cleanliness levels.

Code No.	No. of Particles per Milliliter	Code No.	No. of Particles per Milliliter
30	10,000,000	14	160
29	5,000,000	13	80
28	2,500,000	12	40
27	1,300,000	11	20
26	640,000	10	10
25	320,000	9	5
24	160,000	8	2.5
23	80,000	7	1.3
22	40,000	6	0.64
21	20,000	5	0.32
20	10,000	4	0.16
19	5,000	3	0.08
18	2,500	2	0.04
17	1,300	1	0.02
16	640	0.9	0.01
15	320	0.8	0.005

Table: Typical fluid cleanliness levels required for hydraulic components.

Component	ISO Code
Servo Valves	14/11
Vane and Piston Pumps/Motors	16/13
Directional and Pressure Control Valves	16/13
Gear Pumps/Motors	17/14
Flow Control Valves and Cylinders	18/15

Suction line filtration:

Suction filters are located before the suction port of the pump and provide pump protection against fluid contamination (Figure a). Some may be inlet strainers, submersed in the fluid. Others may be externally mounted.

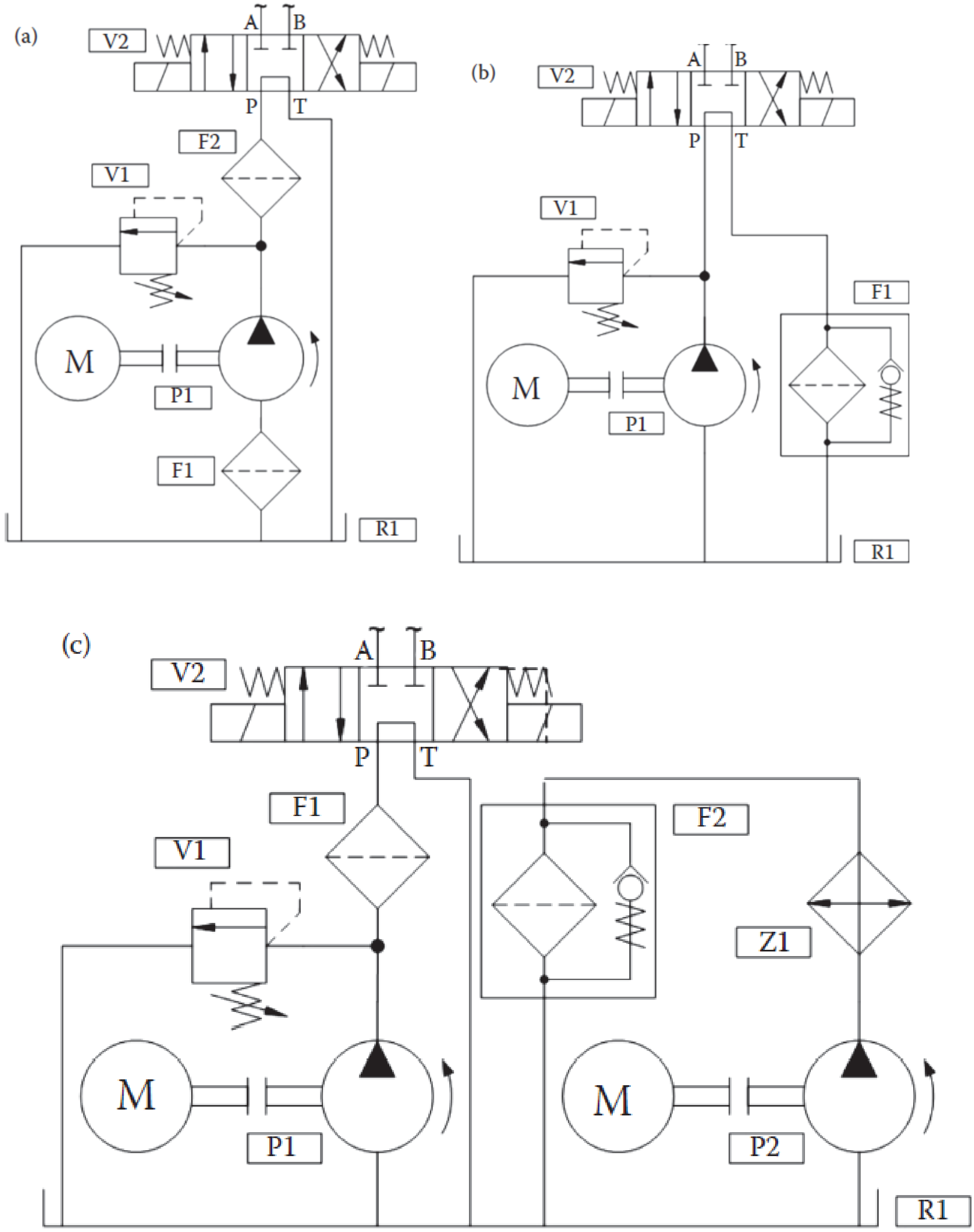


Fig. Types of filtration: (a) Suction filter (F1) and Pressure filter (F2); (b) Return filter (F1); (c) Pressure.

In either case, they utilize relatively coarse elements to avoid high pressure drops that can cause cavitation on the pump. Some pump manufacturers do not recommend the use of a suction filter.

Pressure line filtration: Pressure filters are located downstream of the pump (Figure a and c).They usually produce the lowest system contamination levels to assure clean fluid for sensitive high pressure components and provide protection of downstream components from pump-generated contamination.

Return line filtration: In most systems, the return filter is the last component through which fluid passes before entering the reservoir (Figure b). Therefore, it captures wear debris from system working components and particles entering through worn cylinder rod seals before such contaminants can enter the reservoir. A special concern in applying return filters is sizing for a potential flow rate greater than the pump output, since large rod cylinders and other components can cause induced return line flows. Return lines can have substantial pressure surges, which need to be taken into consideration when selecting filters and their locations. The relatively low cost and the cleanliness of the fluid suctioned by the pump are factors that make the use of these filters attractive.

Re-circulating or off-line filtration: Off-line filtration consists of a hydraulic circuit with at least a pump and its prime mover and a filter. These components are installed off-line as a small subsystem separate from the working lines or can be included in a fluid-cooling loop (Figure c). As with a return line filter, this type of system is best suited to the maintenance of overall cleanliness, but does not provide specific component protection. An off-line filtration has the added advantage of being relatively easy to retract on an existing system that has inadequate filtration. Also, the filter can be serviced without shutting down the main system. The circuits shown in Figures also present some examples of filter installations.

In general, the systems can incorporate multiple filtration techniques, using a combination of suction, pressure, return, and off-line filters.