times the solution to the sink mark problem will lie in altering the finished part
to make the sink mark acceptable. This might include a design over the sink
mark or hiding it from view.

Voids are caused by insufficient plastic in the cavity. The external walls are
frozen solid and the shrinkage occurs internally creating a vacuum. Inadequate
drying of hygroscopic materials and residual monomer and other chemicals in
the original powder may cause the trouble. When voids appear immediately upon
opening the mold, it is probably a material problem. When the voids form after
cooling it is usually a mold or molding problem. Typical causes for voids are
listed below:

Molding Causes

1. Insufficient feed (see section on short shot).
2. Increase the injection pressure.
3. Increase the injection forward time.
4. Increase the boost time.
5. Increase the injection speed.
6. Increase the overall cycle.
7. Change the method of molding (try intrusion).
8. Inconsistent cycles—operator-caused.

Temperature Related Causes

1. Material too hot causing excessive shrinkage.
2. Material too cold causing incomplete filling and packing.
3. Mold temperature too high so that the material on the wall does not set up
   quickly enough.
4. Mold temperature too low preventing incomplete filling.
5. Local hot spots on the mold.
6. Change the cooling pattern.
7. Mold temperature control system malfunctioning.

Possible Mold Changes

1. Increase the gate size.
2. Increase the runner size.
3. Increase the sprue size.
4. Increase the nozzle size.
5. Vent mold.
6. Equalize filling rate of cavity.
7. Prevent interrupted flow into the cavities.
8. Gate in thick sections.
9. Reduce uneven wall thickness where possible. Use cores, ribs, and fillets.
10. Inconsistent cycle—mold-caused.
Machine Changes

1. Increase plasticizing capacity of the machine.
2. Make cycle consistent.

Materials Changes

1. Dry material.
2. Add lubricant.
3. Reduce volatiles in material.

Changes in Cooling Conditions

1. Piece cooled too long in mold, preventing shrinking from the outside in. Shorten mold cooling time.
2. Cool part in hot water.

HOW TO PREVENT POOR WELDS (FLOW MARKS)

Poor welds and flow marks are caused by insufficient temperature and pressure at the weld location. Poor welds have the dismaying proclivity of showing up as broken parts in the field.

Flow marks are the result of welding cooler material around the projection, such as a pin. And their visibility depends on material, color, and surface. Flow marks rarely present mechanical problems, they are inherent in the design of some parts and cannot be eliminated, and this should be kept in mind before the part design is finalized.

Poor welds may be prevented by venting at the weld (where possible), adding a run-off from the weld section may help, increasing the thickness of the part at the weld, lubricating the material and/or local heating of the mold. Ways of eliminating poor welds and flow lines are listed below:

Temperature Problems

1. Too low cylinder temperature.
2. Too low nozzle temperature.
3. Too low mold temperature.
4. Too low mold temperature at spot of weld.
5. Uneven melt temperature.

Molding Problems

1. Inection pressure too low.
2. Injection feed too slow.

Mold Problems

1. Insufficient venting at the weld.
2. Insufficient venting of the piece, therefore add run-off at weld.
3. Runner system too small.
4. Gate system too small.
5. Sprue opening too small.
7. Gate too far from the weld. Add additional gates (these might add additional welds but put them in a less objectionable location).
8. Wall section too thin causing premature freezing.
9. Core may be shifting causing one wall to be too thin.
10. Mold may be shifting causing one wall to be too thin.
11. Part is too thin at weld; thicken it.
12. Unequal filling rate, which should be equalized.
13. Interrupted filling.

Machine Problems

1. Plasticizing capacity too small for the shot.
2. Excessive loss of pressure in the cylinder (plunger machine).

Materials Problems

1. Contaminated material—this can prevent knitting properly.
2. Poor material flow. Lubricate material for better flow.

HOW TO PREVENT BRITTLENESS

Brittleness is caused by degradation of the material during molding. It may be accentuated by a part which is designed at the low limits of mechanical strength. Typical problems and solutions follow.

Molding Problems

1. Low cylinder temperature. Increase cylinder temperature.
2. Low nozzle temperature. Increase nozzle temperature.
3. If material is thermally degrading, lower cylinder and nozzle temperature
4. Increase injection speed,
5. Increase injection pressure,
6. Increase injection forward time,
7. Increase injection boost.
8. Low mold temperature. Increase mold temperature.
9. Part stressed. Mold so that part has minimum stress.
10. Weld lines. Mold to minimize weld line.
11. Screw speed too high, degrading the material.
Mold Problems

1. Part design too thin.
2. Gate too small.
3. Runner too small.
4. Add reinforcement (ribs, fillets).

Materials Problems

1. Contaminated material.
2. Wet material.
3. Volatiles in material. Use material with lower volatile content.
4. Too much reground. Reduce the amount of reground.
5. Low strength materials. Increase strength of material (i.e., add more rubber to high impact polystyrene).

Machine Problems

1. Machine plasticizing capacity too low for the machine.
2. Cylinder obstruction degrading the material.

HOW TO PREVENT MATERIAL DISCOLORATION

Material is often discolored by burning and degradation. This is caused by excessive temperatures, material hanging up somewhere in the system—usually in the cylinder—and flowing over sharp projections such as a nick in the nozzle. The other major cause for discoloration is contamination. This can come from the material itself, poor housekeeping, poor handling, and colorant floating in the air. Causes for material discoloration follow.

Materials Problems

1. Contamination.
2. Material is not dry.
3. Too many volatiles in the material.
5. Colorant degrading.
6. Additives degrading.

Machine Problems

1. Dirty machine.
2. Dirty hopper dryer.
3. Dirty atmosphere. Colorants can float in the air and settle in the hopper and grinder.
These problems may be solved, if you do the following:

a. Clean nozzle,
b. Inspect nozzle and sprue bushing for burrs
c. Purge cylinder
d. Reseat nozzle
e. Clean cylinder and check for burrs
f. Check for cracked cylinder

4. Injection end of machine too large.
5. Thermocouple not functioning.
6. Temperature control system not functioning.
8. Cylinder obstruction degrading the material.

Temperature Based Problems

1. Cylinder temperature too high; decrease temperature.
2. Nozzle temperature too high; decrease temperature.

Molding Problems

1. Decrease screw speed,
2. Decrease back pressure,
3. Reduce clamp pressure,
4. Decrease injection pressure,
5. Decrease injection forward time,
6. Decrease injection boost time,
7. Slow down injection rate,
8. Decrease cycle.

Mold Problems

Degradation and burning this may be prevented, if you do the following.

a. Vent mold,
b. Increase gate size,
c. Increase runner-sprue-nozzle system,
d. Change gating pattern,
e. Remove lubricant and oil from mold,
f. Investigate mold lubricant.

2. Too much stress. Check ejection system. Some rubber based materials such as high impact polystyrene and ABS will discolor on stressing.
HOW TO PREVENT SURFACE DEFECTS (Splay Marks — Mica)

Surface defects are the result of the following:

1. Contamination.
2. Wetness of hygroscopic material and water condensed on nonhygroscopic pellets.
3. Nozzle drool which is picked up by the incoming material and deposited in the mold. This material does not have time to melt.
4. Degraded and burnt material.
5. Jetting, where the material shoots into the mold and exhibits melt fracture.
6. Splay marks or blushing at the gate, caused by melt fracture.
7. Excessive lubricant.
8. Pressure defects which cause characteristic ripples and pit marks.

Splays, mica, flow marks, and surface disturbances at the gate are probably the hardest molding faults to overcome. If molding conditions do not help, it is usually necessary to change the gating system and the mold temperature control. In some cases, the thermal conductivity of the mold material may initiate these surface defects. Sometimes localized heating at the gate will solve the problem. Heating at the gate with a propane torch will determine the advisability of adding a heat sink or a heating cartridge in the gating area. Reasons for defects and some of the solution follow.

MATERIAL PROBLEMS

2. Wet material, which should be properly dried.
3. Nonuniform particle size materials. Therefore, do the following.
   a. Use uniform size particles,
   b. Reduce the amount of fines.

Machine Problems

1. Obstructions. Therefore, do the following:
   a. Check nozzle for partial obstruction.
   b. Check sprue-nozzle-cylinder system for restrictions and burrs.

2. Drool. Therefore, do the following:
   a. Use positive shutoff nozzle to prevent drool,
   b. Use sprue break to prevent drool,
   c. Use suckback to prevent drool.

3. Insufficient machine capacity.
Molding Problems

1. Degradation. Therefore,
   a. Reduce screw speed.
   b. Reduce back pressure
2. If jetting is the cause, reduce injection speed.
3. Alter injection speed,
4. Increase injection pressure,
5. Increase injection forward time,
6. Increase booster time,
7. Increase cycle.

Temperature Problems

1. Too low or too high cylinder temperature depending on problem. Therefore, change temperature profile of cylinder.
2. Too low mold temperature. Therefore raise mold temperature.
4. High nozzle heat may cause drooling. Lower if necessary.

Mold Problems

1. Increase cold slug well,
2. Increase runner extension.
3. Increase runner.
4. Polish sprue runner and gate.
5. Open gate or change gate to tab.
6. Change gate location. If jetting, flare gate or use tab or flared gate.
7. Increase venting,
8. Improve mold surface,
9. Clean mold surface.
10. Excess lubricant. Therefore, do the following:
   a. Use minimum amount of lubricant.
   b. Change type of lubricant.
12. Flow over depressions and raised section. Change the part design.
13. Try localized gate heating.

SURFACE DISTURBANCES AT THE GATE

Splay marks or blushing at the gate is usually caused by melt fracture as the material expands entering the mold. It is usually corrected by changing the gate design and localizing gate heating. The latter can be checked by using a propane
torch to temporarily heat the area. Occasionally it will be necessary to change
the gate location.

Molding Changes
1. Increase barrel temperature.
2. Increase nozzle temperature.
3. Slow down injection rate.
4. Increase injection pressure.
5. Change injection forward time.
6. Use minimum lubricant.
7. Change lubricant.

Mold Changes
1. Raise mold temperature.
2. Increase gate size.
3. Change gate shape (tab or flare gate).
4. Increase cold slug well.
5. Increase runner size.
6. Change gate location.
7. Increase venting.
8. Radius gate at cavity.

Material Changes
1. Dry material.
2. Remove contaminants from the material.

WARPAGE AND SHRINKAGE
Warpage and excessive shrinkage are usually caused by the design of the part, the
gate location, and the molding conditions. Orientation and high stress levels are
also factors. It is recommended that the sections on warpage, shrinkage,
orientation, and crystallinity be reviewed. Warpage and shrinkage can be cured
by the following techniques in the operation.

Molding Changes
1. Increase cycle time.
2. Increase injection pressure without excessive packing.
3. Increase injection forward time without excessive packing.
4. Increase injection boost time without excessive packing.
5. Increase the feed without excessive packing.
6. To reduce warpage lower the material temperature.
7. To reduce warpage keep packing at a minimum.
8. To reduce warpage minimize orientation.
9. To reduce shrinkage raise the material temperature to permit more packing.
10. To reduce shrinkage keep packing at a maximum.
11. Increase injection speed.
12. Slow down ejection mechanism.
13. Annealing parts after molding may reduce warping.
15. Cool in water.
16. Make cycle consistent.

**Mold Changes**

1. Change gate size.
2. Change gate location.
3. Add additional gates.
4. Increase knockout area.
5. Keep knockouts even.
6. Have sufficient venting, especially for deep parts.
7. Strengthen part by increasing wall thickness.
8. Strengthen part by adding ribs and fillets.
9. If differential shrinking and warping is caused by irregular wall sections core, if possible, or change the part design.
10. To reduce warpage reduce the mold temperature to stiffen the outer surface.
11. To decrease shrinkage raise the mold temperature to increase packing.
12. Check mold dimensions. Wrong mold dimensions may cause parts to appear to have shrunk excessively.

**Material.** Use faster setting material.

**HOW TO CONTROL DIMENSIONS**

Dimensional variations are caused by inconsistent machine controls, incorrect molding conditions, poor part design, and variations in materials. Once a part has been molded and the machine conditions set, dimensional variations should maintain themselves within a small given limit. At this point, the quality control department should set these limits and designate which dimensions are to be measured to ensure acceptable parts. When parts vary from accepted standards the problem is usually in a change of molding conditions, but some of these are not readily apparent. For example, a voltage drop will affect the heat output of the cylinder band. The pyrometer will try to compensate, sometimes successfully, sometimes unsuccessfully. At the same time, this same voltage condition will have an effect on motor horsepower and the speed of solenoid operation, which
are not compensated for by the machine circuit. Their effect on dimensional control is rare, but when it does occur it is most difficult to detect. Typical problems are listed below.

**Mold Problems**

1. Incorrect mold dimensions causing parts to appear out of tolerance.
3. Uneven mold filling.
4. Interrupted mold filling.
5. Incorrect gate dimensions.
6. Incorrect runner dimensions.
7. Inconsistent cycle—mold-caused.

**Machine Problem**

1. Malfunctioning feed system in a plunger machine.
2. Inconsistent screw stop action.
3. Inconsistent screw speed.
5. Worn nonreturn valve.
6. Uneven back pressure adjustment.
7. Malfunctioning thermocouple.
8. Malfunctioning temperature control system.
10. Insufficient plasticizing capacity.
11. Inconsistent cycle—machine-caused.

**Molding Problems**

1. Uneven mold temperature.
2. Low injection pressure. Therefore, increase injection pressure.
3. Insufficient fill or hold time. Therefore, do the following:
   a. Increase injection forward time.
   b. Increase injection boost time.
4. Too high barrel temperature. Therefore, lower barrel temperature.
5. Too high nozzle temperature. Therefore, lower nozzle temperature.

**Materials Problems**

1. Batch to batch variation.
2. Irregular particle size.
3. Wet material.
HOW TO PREVENT STICKING IN MOLD

Parts stick in the mold primarily because of molding defects, insufficient knockout, packing of material into the mold, and incorrect mold design. If parts stick in the mold, it is impossible to mold correctly.

Parts stick when molding conditions cause the material to pack into the cavity. This will expand the cavity, force the plastic into microscopic depressions, and reduce the amount of normal shrinkage, which would ease ejection from the cavity. Deformation of cavity and core are common causes for mold release problems.

Theoretically, mold release agent should not be required. Practically this is not the case. The two most widely used lubricants are the heavy metallic salts of stearic acid, such as zinc stearate, applied as a powder, and silicone compounds. The silicones are mixed with the necessary solvents and propellants. They are dispensed from aerosol cans, self-propelled pressure systems, and bulk containers using air or Freon as the propellant. It is necessary to select the right solvent which does not affect the material being molded. Mold releases can cause difficulties in painting, decorating, and metallizing (3). Remember also that excess lubricant does not increase mold release. The most costly part of using lubricants is the cycle time lost by the operator during its application. A new method of permanently lubricating the cavity consists of impinging a 0.0002 to 0.0004-in. layer of graphite mixture into the metal surfaces of the mold with a patented air gun (4). The remaining graphite acts as a lubricant.

Nonetheless parts do stick. Their removal can cause severe mold damage. Steel should never be used on the mold by an operator. Hard wood, soft brass, and soft copper are materials of choice. Occasionally it is necessary to heat a screw or a broken hacksaw blade and force it into the molded part. After cooling the screw and blade are used as handles to release the molded part. Occasionally blowing air across the surface of a deep molded part will cause its release. This is particularly true if the part has been allowed to shrink for a moment. Typical solutions follow.

Mold Remedies

1. See if sticking is caused by short shot not engaging knockout system.
2. Remove undercuts.
3. Remove burrs, nicks, and similar irregularities,
4. Remove scratches and pits.
5. Improve the mold surface.
6. Restone and polish using movements only in the direction of ejection. This is called draw polishing.
7. Ascertain if the mold surface is correct for the material being molded.
8. Increase the taper.
9. Increase the effective knockout area.
10. Change the knockout location.
11. Check the operation of the knockout system (plates might not be moving in the proper sequence, cams loose, etc.)
12. See if the cams are clearing before the part is ejected.
13. Add vacuum breaks and air ejection in deep drawn moldings.
14. Check if the core is shifting during molding. This can be done by measuring wall thicknesses.
15. See if the cavities are deforming during molding.
16. See if the mold base is deforming during molding. This should be carefully checked when there is a large projected area perpendicular to the clamping force. Often there is not enough steel in the supporting pocket.
17. Check if the mold shifts when opening. Items 14 to 17 are suspects when there is scratching or rubbing on the outside of the part near the parting line. Shifting can be caused by the mold or machine.
18. Decrease the gate size.
19. Add additional gates.
20. Relocate the gates. The purpose of items 18 to 20 is to decrease the pressure in the cavity.
21. Equalize the mold filling rate.
22. Prevent interrupted filling.
23. Determine whether the part is strong enough for ejection.
24. Radius and reinforced parts giving greater rigidity.
25. See if the parts are degrading and losing mechanical properties.
26. Add additional knockout systems such as air ejection.
27. Redesign the part.
28. If the part remains on the wrong side you can undercut the other side, change tapers, and provide mold temperature differentials.
29. Make inconsistent mold-caused cycles consistent.

Molding Remedies

1. Use more mold release agent (if insufficient).
2. Use proper mold release agent (if wrong agent).
3. Reduce material feed.
4. Reduce injection pressure.
5. Reduce injection forward time.
6. Reduce injection boost time.
7. Reduce mold temperature.
8. Increase overall cycles. This lowers the temperature making the part more rigid and increases the amount of shrinkage.
Materials Solutions

1. Remove contamination in the material.
2. Add lubricant to the material
3. Dry the material.

Machine Solutions

1. Repair any malfunctioning of the knockout system.
2. Lengthen insufficient knockout travel distance (if insufficient)
4. Check to see if platens are parallel.
5. Check the tie rod bushings.

HOW TO PREVENT STICKING IN THE SPRUE

Sprue sticking is caused by improperly fitted sprue-nozzle interface, pitted surfaces, inadequate pull-back, and packing. Occasionally the sprue diameter will be so large that it will not solidify enough for ejection at the same time as the molded parts. Here is how sticking may be prevented.

Sprue Solutions

1. Match sprue radius to nozzle radius if mismatched.
2. Correct sprue-nozzle seating.
3. Make sure that nozzle orifice is not larger than sprue orifice.
4. Polish the sprue,
5. Increase the taper of the sprue.
6. Increase the sprue diameter if it is too weak.
7. Decrease the sprue diameter if it is too large for cooling.
8. Control temperature of sprue (rare).

Mold Solutions

1. Increase the pull-out force of the spure-puller system.
2. Reduce mold temperature.

Molding Solutions

1. Use sprue break (machine moves back slightly, breaking contact between nozzle and sprue).
2. Increase suckback.
3. Reduce feed.
4. Reduce injection pressure.
5. Reduce ram forward time.
6. Reduce injection boost time.
7. Reduce material temperature.
8. Reduce cylinder temperature.
9. Reduce nozzle temperature.

**Materials Solutions**

1. Check for material contamination.
2. Dry material.

**HOW TO PREVENT NOZZLE DROOLING**

Nozzle drooling is caused by overheated material. For a material with a sharp viscosity change at molding temperature such as nylon, the use of a reverse taper nozzle or a positive-seal type of nozzle is recommended. The objection to nozzle drooling is that it introduces solidified material into the part which causes surface defects. It may also interfere with the flow and mechanical properties. Typical solutions to nozzle drooling follow.

**Nozzle Solutions**

1. Use positive-seal type nozzle.
2. Use reverse taper nozzle.
3. Reduce nozzle bore diameter.

**Molding Solutions**

1. Reduce nozzle temperature
2. Increase suckback.
3. Use sprue break.
4. Decrease material temperature.
5. Reduce injection pressure.
6. Reduce injection forward time.
7. Reduce injection boost time.

**Mold Solutions**

1. Increase cold slug well.
2. Increase run-off.

**Materials Solutions**

1. Check for contamination.
2. Dry the material.

**HOW TO SOLVE THERMOSET MOLDING PROBLEMS (5)**

The differences between thermoplastic and thermoset trouble shooting derive from the irreversible plasticity of thermosetting materials. The temperature in the cylinder and nozzle must be low enough to prevent premature setup. The
temperature of the mold sets the material. Therefore, raising mold temperature increases viscosity and decreases pressure transmission. Listed below are those areas where the method of correcting molding faults differ.

**Screw Wear, Screw Squeaking Problems**

1. Decrease screw speed.
2. Decrease back pressure.
3. Decrease cylinder temperature.
4. Lubricate material.

**Blistering on Material**

1. Increase back pressure.
2. Increase injection pressure.
3. Increase feed.
4. Increase mold temperature.
5. Increase cycle time.
6. Increase gate size.
7. Increase runner size.
8. Increase cavity vents.

**Setup Problems of Material in Cylinder**

1. Reduce cylinder temperature.
2. Reduce screw speed.
3. Reduce back pressure.
4. Reduce nozzle temperature.
5. Increase nozzle opening.
6. Clean (flush) screw.
7. Maintain even cycle.

**Material Setting up in Nozzle**

1. Lower nozzle temperature.
2. Lower cylinder temperature.
3. Open nozzle hole.
4. Use sprue break if there is excessive heat transfer from the mold to the nozzle.
5. Clean the nozzle.
6. Decrease screw speed.

**Accomplished by Changing Mold Temperature**

1. Increase mold temperature to minimize or cure the following;

   a. Parts blistered.
b. Flashed mold.
c. Incompletely cured (flexible) parts.

2. Decrease mold temperature to minimize or cure the following:
   a. Flow lines.
   b. Dull surface.
   c. Mold stains.
   d. Sticking parts.
   e. Nonfilled parts.
   f. Porous parts.
   g. Entrapped gas.

**HOW TO PREVENT EXCESSIVE CYCLES**

Excessive cycles are usually caused by poor management. Proper records are not kept, standards not established, and constant monitoring of output not established. Most jobs could have their cycles reduced by an experienced molding superintendent. In practice unfortunately, these new reduced cycles will very often slowly creep back to the original cycle. Other causes of excessive cycles are insufficient plasticizing capacity, inadequate cooling, channels in the mold, insufficient cooling fluid, and erratic cycles. Problems by type follow.

**Management Problems**

1. Nobody in authority cares.
2. Incorrect, poor, or nonexistent records.
3. Incorrect setting of controls.
4. Unauthorized cycle changes.
5. Nonmonitoring of cycle time.
6. Too much for the operator to do.

**Machine Problems**

1. Malfunctioning of the machine.
2. Platen slow down time excessive.

**Mold, Molding and Materials Problems**

1. Insufficient cooling capacity in mold.
2. Insufficient cooling capacity in chillers.
3. Material temperature too high.
4. Material too slow in setting up.
5. Material contaminated.
6. Inconsistent cycle — mold-caused.
HOW TO BREAK IN NEW MOLD

The following information is helpful in breaking in a new mold. This is a critical step in a molding plant and requires the utilization of the best talent. A plant that can get a new mold in operation in a minimum of time and with minimal or no help from the moldmaker has a definite competitive advantage. The following procedures will help in that respect and tend to eliminate or minimize mold damage.

1. If a mold is "new" to the shop but has been run before, obtain samples and as much information as possible.
2. Clean the mold carefully.
3. Visually inspect the mold. This is the time for questions, consultations, and changes. Obvious corrections, such as improving the polish or removing undercuts, should be done before the mold is put in. The object is to put a mold in that will produce satisfactory parts.
4. Understand the actions of the mold and try cams, slides, locks, unscrewing devices, and such on the bench.
5. Install safety devices. For example, if a knockout plate must be back before the mold closes, electrical interlocks should be installed. It is very easy to damage a mold this way during the break-in period.
6. Put the mold into the press and move very slowly under low pressure.
7. Open the mold and inspect it again.
8. Dry cycle the mold without injecting material. Check knockout stroke, speeds, cushions, and low pressure closing.
9. Bring mold to operating temperature and dry cycle again. Expansion or contraction of the mold parts may effect the fits.
10. Take a shot using maximum mold lubrication and under conditions least likely to cause mold damage. These are usually low material feed and pressure.
11. Build up slowly to operating conditions. Run until stabilized, at least 1 hr.
12. Record operating information.
13. Take part to quality control for approval.
14. Make required changes.
15. Repeat process until approved by quality control and/or customer.
16. Record all the information on the appropriate record forms.
CHAPTER 6

Hydraulic Mechanisms and Circuits

Hydraulics is the study of mechanical properties of liquids and their applications in engineering. Three forms of energy are found in oil hydraulic systems — heat, kinetic energy, and potential energy. Heat energy, the result of the flow of oil, is caused by the internal friction of the oil molecules flowing over themselves and over the walls of their containments. Heat energy is undesirable because it is not useful in the process and in addition must be removed from the system. A certain amount of heat is generated because of the nature of the pump and the hydraulic mechanisms. Excessive heat is caused by excessive length of flow, excessive bends, turns and obstructions, insufficient pipe diameter, inefficient or worn parts, and incorrect design. A further discussion of this topic is beyond the scope of this text.

Kinetic energy is the energy of motion. Its main effect is in terms of velocity. We attempt to minimize the kinetic energy of a hydraulic system in molding machines. Velocity, which is distance per unit time (such as feet per second), should not be confused with volume (amount of flow) which has the dimensions of quantity per time (such as gallons per minute). We are primarily concerned with the potential or pressure energy. Pressure is created by resistance to flow. It implies a closed or throttled system with a source to supply oil. This normally is a pump or an accumulator (a container of oil with a compressed gas exerting force behind it).

HYDRAULIC MECHANISMS

The three types of matter react differently to a force (Figure 6-1). A gas will compress. A solid will transmit the force in the direction of the applied force. A
liquid obeys Pascal's law, which states that, in a static liquid, pressure acts equally in all directions and will be transmitted undiminished in all directions and act with equal force on all equal areas (Figure 6-2). An irregularly shaped container filled to the top and covered with a floating seal with an area of 1 in.\(^2\) has a 10-lb weight placed upon it. The liquid under the seal has a pressure of 10 lb/in.\(^2\) (psi). Every square inch of surface of this container has a 10-lb force acting perpendicular to it. If the surface had an area of 1000 in.\(^2\) then the total force on the container would be 1000 in.\(^2\) \(\times\) 10 psi, or 10,000 lb. Thus a 10-lb force has now become a 10,000 lb force.

This is the principle of the hydraulic jack, (Figure 6-3). An hydraulic pump consists of a hand operated piston with a 1-in.\(^2\) area in a cylinder. When the piston is raised it lowers the pressure in the cylinder. Atmospheric pressure forces the oil from the tank through check valve B into the pump. Check valves allow flow in one direction and block flow in the other direction. (The symbols
Figure 6-2 Illustration of Pascal's law—"In a static liquid, pressure acts equally in all directions and will be transmitted undiminished, in all directions. It will act with equal force on all equal areas."

are those of the American Standard Association and adopted by the Joint Industry Conference (J.I.C.) which are used in hydraulic circuitry (Figures 6-4 and 6-5). The new standards were adopted in December 1966. Since the old symbols have been used on most injection molding machine hydraulic drawings, both old and new symbols will be used in the book.) Oil can not go through check valve A because the force generated by the weight of the jack will be high enough to keep it closed. The piston in the cylinder is now pushed down with a force of 100 lb. The oil is blocked at check valve B and goes through check valve A underneath the jack raising it. The jack is another piston in a cylinder. The portion above the piston is vented to tank to remove any oil
leakage past the seals. The area under the piston of this jack is 50 in.\(^2\). Since we are pushing with a pressure of 100 psi the total force on the top of the jack will be 50 in.\(^2\) \times 100 \text{ psi} or 5000 lb. Thus a force of 100 lb is converted into one of 5000 lb. The pumping action is repeated until the jack reaches the maximum movement desired or available. To return the jack to its starting position or to a lower position, oil is returned from underneath the jack to the tank through the manually operated two way valve. Any number of jacks, each with different surface areas, could be fed simultaneously from the same pump.

Figure 6-3 The principle of the hydraulic Jack.
One should not confuse force \((F)\), pressure \((p)\), area \((A)\), work \((W)\), and power \((P)\). They are related as follows:

\[
F = pA \\
W = F \times \text{(distance)} \\
p = \frac{FD}{t} = \frac{W}{t} \\
t = \text{time}
\]

The pump side has a force of 100 lb on an area of 1 in.\(^2\) giving a pressure of 100 psi. The jack side has this pressure (100 psi) on an area of 50 in.\(^2\) for a force of 5000 lb. Obviously they are not going to move the same distance or energy would be created in the system. This is shown by the work done on each side which must be the same (neglecting heat energy losses). On the pump side the
Figure 6-5  Fluid power symbols (new). USAS Y32.10 12/66.
100-lb force has moved 10 in. for work of 1000 in.-lb. On the jack side the force of 5000 lb has moved 0.2 in. for the same amount of work — 1000 in.-lb. If one pumping stroke was done each second then the power of the system would be 1000 in.-lb/sec.

Advantages and Disadvantages of Hydraulic Systems

From Pascal's law and the operation of a jack, some reasons for the advantages and disadvantages of hydraulics in a molding machine can be deduced.

Advantages of a Hydraulic Systems

1. The parts and mechanisms can be located in any place.
2. The force can be transmitted around corners and in all directions.
3. The oil is not subject to damage or breakdown in the same degree as mechanical linkages, cams, gears, and such.
4. The motion is transmitted throughout the system with little slack.
5. The power is transmitted rapidly at a long distance with small loss.
6. The speed and force can be controlled in stepless increments between limits.
7. Large forces can be applied with no motion.
8. It is relatively unaffected by variations in load and by stalling. When stalled, the volume requirements are low.
9. Large forces can be generated by small compact units and can be controlled by much smaller forces. Forces can be multiplied.
10. Action is smooth with no vibration and with an inherent cushion effect.
11. Automatic control is easily obtained.
12. Overload and breakdown protection can be built in.
13. Nonproductive energy (heat) can be absorbed and easily dissipated.
14. Because oil is the hydraulic fluid, lubrication is automatic and there is little wear.
15. Maintenance is low.
16. By means of gages there is a continuous indication of the state of the system.
17. Reciprocating motion is easily obtained.
18. Repair parts are readily available and can be made in local machine shops.
19. Since there is low power consumption, it is an economical method of operation.
20. It is a comparatively silent system.

Disadvantages of Hydraulic Systems

1. It must be a totally confined system.
2. Leaks must be prevented. This can present problems when working in the pressure ranges of modern machines.
3. Mechanical requirements of all the parts of the system are relatively large.
4. The heat-energy built up must be removed.
5. Moisture vapor and water must be kept out of the system.
6. The oil must be clean and contain the proper additives to prevent formation of sludge and gums which would impair the proper functioning of the machine.
7. Oil and oil reclamation are relatively costly.
8. Hydraulic oils are a fire hazard.
9. Personnel are usually more familiar with electrical and mechanical systems.

It can be seen that for injection molding machines the advantages of an hydraulic system far outweigh the disadvantages.

HYDRAULIC OILS – REQUIREMENTS

Five basic properties are required of a good hydraulic fluid: oxidation stability, rust prevention, water separating ability, resistance to foaming, and lubrication. These require little consideration by the molder since, with normal care, they will maintain themselves (1, 2).

Oxidation stability is the resistance of an oil (hydrocarbon) to chemical reaction with oxygen (oxidation). Without it, the first products formed are unstable hydroperoxides which react to form other chemicals, including acids, all of which are soluble in oil. These will in turn react with each other and polymerize, producing soluble resins first and later, insoluble resins. Soluble resins change the viscosity of the oil, soluble acids tend to increase its corrosive action, and the insoluble resins precipitate out. This reduces clearances, plugs up small holes, clogs the filter, and reduces the operating efficiency of the system, eventually leading to a complete breakdown.

Oxidation is a chemical process whose rate approximately doubles for every 18°F increase in temperature. Because of this and viscosity changes the average temperature of the oil should not exceed 130°F. There will be parts of the system which are operating at higher temperatures. Since oxygen is supplied by air and trapped in the hydraulic system, it is present in the oil in appreciable amounts. The metals, particularly copper, catalyze the oxidation of oil. This is why copper tubing is not used, even though its other properties would make it desirable. Small particles of iron are also excellent catalysts. These come from the wearing of metallic parts as well as from unintentional contamination. A permanent magnet should be placed in every reservoir and cleaned periodically. This will not only reduce oxidation by removing the particles, but also help prevent excessive frictional wear.
**Rust formation** is caused by water which appears in the hydraulic system through atmospheric condensation. In addition, water used as a cooling medium in molds and on machines, may possibly leak into the hydraulic system. It does not take much water to introduce rust into the system. Corrosion not only causes damage to parts, but the abrasive action of iron oxide (rust) circulating in the system will cause additional damage. Rust is prevented by an additive which has great affinity for metal surfaces. It forms a film that resists displacement by water.

**The water separating** ability of oil is basically present and is obtained in the refining process rather than from additives. Water is always present in the oil because of atmospheric condensation and possible accidental addition. It emulsifies with oil and its contaminants form slurries which can foul up pumps, controls, and cylinders. The water separating or demulsifying properties of the oil cause the water to separate out and thus prevent slurry formation. This property is also useful when the oil is purified outside the hydraulic system by means of separating tanks.

**Resistance to foaming** is required in a good hydraulic oil. The oil usually has about 10% by volume of dissolved air, which normally remains in solution and causes no trouble. Oil can absorb a considerable amount of air when under pressure. When this pressure is released, the air will come out of solution and may produce foam. Trapped air has serious consequences in the system. Oil cannot be compressed easily, but the air can. Temperatures of 1000°F are possible through rapid compression of air such as occurs in the cylinders and pump. This is not observable on the oil temperature indicator which reads only the average oil temperature. The oil immediately surrounding the hot spot will oxidize — an undesirable condition.

Most foaming in injection molding machine systems is due to mechanical causes. These include air leaking in suction lines, too low an oil level, leaking packing, improper functioning of air bleeders, drains discharging above the oil level, and certain deficiencies in the design of the hydraulic system. The latter should not be true of original equipment, but develops through modifications in the molding plant.

**The lubricating properties** are normally taken for granted. It should be noted that hydraulic oil has excellent antiwear properties compared with other oils of similar viscosity. The higher the viscosity, the better the film strength or antiwear properties. This is the reason for selecting an oil of high viscosity and is another important reason for keeping the temperature of the system low. The higher the temperature, the lower the viscosity.
VISCOSITY

Viscosity is the most important single property of hydraulic oils. It is a measure of the shearing stress or the resistance to flow of sliding layers of molecules. It is equal to the tangential or shearing force on two parallel plates of unit area at a unit distance apart moving at a unit velocity in relation to each other. The viscosity, therefore, is the shear stress divided by the shear rate. The shear stress is shown as force per unit area. The shear rate is the volumetric flow rate divided by the volume.

\[
\text{Absolute viscosity } (\mu) = \frac{\text{shear stress } (\tau)}{\text{shear stress } (\gamma)} = \frac{F/L^2}{(V/t)V/L^2} = \frac{F}{L^2} \cdot \frac{t}{L}
\]

where \( F = \text{force} \)
\( L = \text{length} \)
\( V = \text{volume} \)
\( t = \text{time} \).

The units of absolute viscosity in the English and metric systems are shown below. The viscosity of water at 20°C equals 1 cp.

<table>
<thead>
<tr>
<th>English system</th>
<th>Metric system</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{lb}-\text{sec}}{\text{in.}^2} = \text{reyn} )</td>
<td>( \frac{\text{g}}{(\text{cm})(\text{sec})} = \frac{(\text{dyne})(\text{sec})}{\text{cm}^2} = \text{P} )</td>
</tr>
<tr>
<td>1 ( \frac{\text{lb} - \text{sec}}{\text{in.}^2} = 6.89 \times 10^4 \text{ P} = 6.89 \times 10^6 \text{ CP} )</td>
<td></td>
</tr>
</tbody>
</table>

The kinematic viscosity \( (\nu) \) is the absolute viscosity divided by the mass density \( (\rho) \). Mass density is the weight per unit volume divided by the acceleration of gravity. In metric units the mass density is the same as the specific gravity. The units for the kinematic viscosity follow.

<table>
<thead>
<tr>
<th>English system</th>
<th>metric system</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{(\text{lb})(\text{sec})/\text{ft}^2}{(\text{lb/ft}^3)/(\text{ft/sec}^2)} = \frac{\text{ft}^2}{\text{sec}} )</td>
<td>( \frac{[\text{g}/(\text{cm})(\text{sec})]}{(\text{gm/cm}^3)} = \frac{\text{cm}^2}{\text{sec}} = \text{St} )</td>
</tr>
<tr>
<td>1 ( \frac{\text{ft}^2}{\text{sec}} = 929 \text{ St} = 9.29 \times 10^4 \text{ cSt} )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>English system</th>
<th>metric system</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{sec}}{\text{in.}^2} = 6.45 \text{ St} = 645 \text{ cSt} )</td>
<td></td>
</tr>
</tbody>
</table>
Viscosity

The English system has no unit for kinematic viscosity. The conversion is made by changing from cm²/sec to in.²/sec (dividing centistokes by 645) or ft²/sec to cm²/sec (dividing centistokes by 9.29 × 10⁴).

The viscosity of oil is measured in Saybolt universal seconds (SSU or SUS). It is reported in the number of seconds it takes for 60 cc of oil at 100°F to pass through a standard orifice 0.0695 in. diameter and 0.483 in. long. Viscosity of oil used in molding machines ranges from 150 to 300 SUS. It can be converted into kinematic viscosity by the following empirical formula:

\[ \nu = 0.226t - \frac{195}{t} \quad t < 100 \text{ SUS} \]

\[ \nu = 0.220t - \frac{135}{t} \quad t > 100 \text{ SUS} \]

(6-2)

where

\[ \nu = \text{kinematic viscosity (c St)} \]

\[ t = \text{seconds (SUS).} \]

As oil is heated the distance between the molecules expands lowering their resistance to flow, or viscosity. The viscosity index is a measure of the effect of temperature on viscosity. It is an empirical number based on the viscosity/temperature relationship of two specified oils. The viscosity index of hydraulic oils for molding systems should not be less than 78.

The factors that make for inefficiency in an hydraulic system are mainly slippage in the pump, internal leakage in the control components, cavitation, oil leakage, fluid friction, mechanical friction, and the rate of response. These are all affected by viscosity.

Effects of Too High Viscosity

If the viscosity of the oil is too high, more force will be required to move the same volume of fluid. Since this energy is nonproductive, it will reduce the efficiency of the system. Too viscous an oil can also cause cavitation.

Furthermore, viscous oil is not sucked into the pump in sufficient quantities so that a relatively high vacuum is produced within the pump. This phenomenon lowers the vaporization point of the oil which then begins to vaporize. Air dissolved in the oil is released, air pockets form and then collapse when the vacuum is reduced. When this happens the pump becomes noisy and vibrates during pump operation. The noise and vibration shortens the life of the pump. (Plugged intakes, clogged filters, improper design such as intake connections that are too small, or any oil starvation of the pump will cause the same thing.) Finally, high viscosity oils, which on the one hand increase the lubricity of the oil, may cause sluggish response in the valves on the other hand.
Effects of Too Low Viscosity

The undesirable effect of excessively low viscosity are excessive internal and external leakage, slippage in the pump, increased rate of wear on moving parts, larger pressure drops in the system, increased temperature, and a lowering of efficiency. The lower viscosity gives fast control action and trouble free cold starting. The selection of the viscosity and viscosity index of the oil is a compromise.

Operating Range

The maximum operating temperature range for molding machines is 40 to 150°F. The viscosities of the oils outside of this range will cause improper operation of the machine and possible damage. Since leakage in a cylindrical part increases as the cube of the clearance between the parts, these clearances are held to close tolerance. If the temperature is not properly controlled, clearances will change because of the differential expansions of the piston and the spool. This, and a lowered lubricity of the oil at high temperatures, can cause severe wear and even galling.

Fire Resistant Fluids

Fire resistant hydraulic fluids (3) have been developed for those locations where there is danger of ignition of the hydraulic fluid caused by failure of a pressure line or components. There are two types—water based and chlorinated or phosphate ester based. Neither are as desirable as hydraulic oils. Should conversion be required consultation is needed with the machinery manufacturer. Seals, packing, paint, and other components may have to be changed.

MAINTENANCE OF HYDRAULIC OILS

Experience has shown that hydraulic systems treated with a reasonable amount of care will seldom cause trouble. When trouble does occur, it is usually very costly in terms of down time and repair. Luckily, difficulties in the system occur before a total breakdown and the experienced molder will take advantage of these warnings to remedy the faults in the system. For example, dirty oil can cause improper functioning of valves which can lead to erratic molding. Overheating of the oil can be detected by increased power consumption which is also costly.

It has been estimated that 70% of hydraulic trouble is caused by the improper condition of the hydraulic oil.
Contamination

There are two types of contaminations:

1. Contaminants resulting from degradation of the hydraulic oil itself,
2. Contaminants resulting from the addition of foreign materials (which include plastic, water, packing and gasketing material, metal particles, and rust).

The deleterious effects of high operating temperatures on oil must be reemphasized. The decomposition of oil is rapidly accelerated, once the process starts, by the decomposition products formed.

The major source of accidental contamination is during the transfer of the oil from the drum to the machine. All drums should be stored indoors and on their side. The best means of transfer is by blowing from the drum to the machine. Needless to say, the top of the drum, the bung, the filler hole of the machine, and the connecting system must be scrupulously clean.

Water accumulates in the hydraulic system because of atmospheric conditions. When a machine is shut down the heated air above the reservoir can contain more water than does air at room temperature. Upon cooling under certain conditions, water will condense. Continual repetition of this process will introduce an appreciable amount of water into the oil. One of the major contaminants to be checked, therefore, is water.

Oil will also receive contamination from the dusty atmosphere. Dust settles on the exposed parts of the hydraulic system, and is washed back through the packing and into the oil. Fine particles of iron are a normal result of wear. These will be removed by a magnet placed in the reservoir.

The final source of outside contamination is dirt which enters the system during machine repairs. Before the hydraulic system or any part of it is exposed, the working areas should be thoroughly cleaned and all tools wiped. If the job cannot be completed at once, the opening and surrounding areas should be covered.

Despite every effort, contaminants will get into the system. The purpose of maintenance is to keep these under control so that the machine can function properly. The better method of controlling oil purity is through straining and filtration (4). A strainer is a device for the removal of solids from a fluid, where resistance to the motion of the solid is in a straight line, such as a wire mesh screen. A filter is a device for the removal of solids from a fluid where resistance to motion of such solids is in a tortuous path, such as cellulose or fibers.

A strainer should be put before every pump. They are constructed to bypass the strainer when it is dirty. This will prevent cavitation of the pump, but not damage by contaminants. There is an indicator telling when the strainer should be cleaned.

Continuous filtration should be provided on every machine. A larger capacity filter of the same type, which should be able to heat the oil before filtration,
should be available to be installed on a particular machine if required.

Oil can be reclaimed by putting it in a settling tank for at least 24 hrs. The sludge and water is drained from the bottom. The remaining oil is recirculated through a filter until it looks clean and nothing precipitates out upon standing. A sample should be sent to the manufacturer to check the condition of the oil and see if any additives are required. Periodic samples of oil from each machine should be taken and allowed to settle. Regular inspection of any precipitated sludge or water and the “sparkle” of the oil is a good indication of the state of the system.

Figure 6-38 shows an oil filtration circuit with its own motor and pump. Figure 6-6 shows an oil filtration circuit where the supply of oil is from one of the main return or tank lines. It can be from the main pressure relief valve, an unloading valve, a cylinder, or a four way valve. If the filter is clogged, and the pressure is over 60 psi, the overload check valve will open bypassing the return of load to tank. The filter can be changed while the machine is in operation by closing the shut-off valve. The oil will then return over the check valve. The gauge reading will be a measure of the resistance in the filter which is a function of the amount of dirt.

Gauges

Gauges are used in hydraulic machines to measure the pressure at various points in the system. There are at least two gauges on the injection machine; one measures the injection pressure and the second the clamping pressure. The pilot system will have a gauge if it is in a different pressure range.

It is essential that gauges function properly and be kept in good condition, since many molding problems can be traced to malfunctioning gauges. For example, a particular molding job is known to require a 1500-psi gauge reading on the clamping circuit. If the gauge is incorrect and there are actually only 900 psi the pressure may not be enough to prevent flashing of the mold. The gauge is usually the last thing checked. Gauges usually fail because of pressure surges. A snubber should always be used with a gauge. Its purpose is to cushion the shock of the oil. Cut-off valves for pressure gauges are especially designed with slow opening speeds to prevent sudden pressure surges.

The gauge most commonly used for measuring pressure in the injection machine is a Bourden-type gauge which works on the principle that oil pressure in a curved tube will cause the tube to straighten out, and that the amount of straightening is directly proportional to the pressure. They are accurate to approximately 0.3% of the full scale reading. They are relatively fragile but can often be repaired by maintenance personnel. When this is done the readings should be compared with a gauge of known accuracy or a dead weight tester.

The plunger type gauge is a relatively rugged, reliable gauge, slightly less accurate than is the Bourden-type. The liquid whose pressure is being measured
Figure 6-6 Oil filtration circuit.

actuates a piston to which is attached an indicator. The piston is held in place by a spring, and the force of the oil compresses the spring, lifting the valve and the indicator out of the body. It is very useful in the maintenance department, particularly when checking out pumps and other hydraulic components where sudden surges of pressure occur. It is not used as an operating pressure indicator, because of the higher accuracy of the Bourden-type gauge.

The pressure indicated by either gauge is the pressure of the system, excluding atmospheric pressure. Thus it is called gauge pressure. Absolute pressure is a system's pressure plus atmospheric pressure and is never used on molding equipment. Gauges in the hydraulic system are comparable to meters in the electrical system. They are continuing indicators of the operation, and are
invaluable in hydraulic trouble shooting.

CONNECTORS

The power to operate the molding machine, generated in the pump, must be transmitted to the cylinders and hydraulic motors which are the working components of the machine. The hydraulic power transmission lines in the injection molding machine are steel pipes, steel tubing, and rubber covered flexible braided wire hose (5). The choice of these transmission units depends on the flow and pressure requirements of that portion of the system for which they are designed (6).

The proper selection of the power transmitting units or piping and their connectors are of primary importance. This is adequately done on new equipment. Many of the older machines in use today can benefit from the improved knowledge and experience that has been accumulated. Leaks in transmission lines and connectors often develop in the same place, and are detected by a good maintenance program. The reasons for the breakdowns should be analyzed and the condition corrected.

Transmission lines and their connectors are fully treated in many references and in manufacturers’ bulletins. A brief discussion follows.

Steel Pipe Tubing, Hose

Steel pipe has a minimum tensile strength of 60,000 psi, a minimum yield point of 35,000 psi, and an allowable stress in the steel (S value) of 15,000 psi. The inside diameter will be determined by flow considerations. The wall thickness is generally determined by various codes. For molding machines Barlow’s formula is used. Pipes are sized by schedule numbers which are related to the ratio of the allowable stress in the pipe over the allowable stress in the pipe material. Table 6-1 shows some dimensions and properties of pipe used in molding machines.

Hydraulic piping is connected by threading and welding. Threading alone is not completely satisfactory. Pipe compound can be used over the threads; however, the preferable method is to use a Teflon tape which is wound once around the thread and overlapped by a 1/2 in., after which the thread is screwed tight. Threaded fittings have certain disadvantages. Aside from weakening of the wall, there are flow turbulences generated because of the enlargement and reduction of the cross-sectional areas. These disadvantages can be overcome by welding. Forged steel fittings of the socket welding type are available in Schedule 80 and 160 for use on molding machines. They are easily installed by slipping the pipe into the fitting and then welding. This technique provides a strong joint resistant to shocks and vibration without the turbulence and
Table 6-1  Dimensions and properties of ASTM A106 grade B pipe (working pressures calculated from ASA B31.1 where 
\( y = 0 \) (Barlow's formula), \( S = 15,000 \) psi \( C \) plain end value, and manufacturer's tolerance are \( 12\% \).

<table>
<thead>
<tr>
<th>Nominal Pipe Size (in.)</th>
<th>Threads (per inch)</th>
<th>O. D. (in.)</th>
<th>Length of Thread Screwed Into Fitting</th>
<th>I. D. (in.)</th>
<th>Nominal Wall Thickness</th>
<th>Schedule 80</th>
<th>Schedule 160</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/8</td>
<td>27</td>
<td>0.405</td>
<td>1/4</td>
<td>0.215</td>
<td>0.095</td>
<td>1.1</td>
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</tr>
<tr>
<td>1/4</td>
<td>18</td>
<td>0.540</td>
<td>3/8</td>
<td>0.302</td>
<td>0.119</td>
<td>2.2</td>
<td>3000</td>
</tr>
<tr>
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<td>18</td>
<td>0.675</td>
<td>3/8</td>
<td>0.423</td>
<td>0.126</td>
<td>4.4</td>
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</tr>
<tr>
<td>1/2</td>
<td>14</td>
<td>0.840</td>
<td>1/2</td>
<td>0.546</td>
<td>0.147</td>
<td>7.3</td>
<td>2810</td>
</tr>
<tr>
<td>3/4</td>
<td>14</td>
<td>1.050</td>
<td>9/16</td>
<td>0.742</td>
<td>0.154</td>
<td>13.5</td>
<td>2410</td>
</tr>
<tr>
<td>1</td>
<td>11 1/2</td>
<td>1.315</td>
<td>11/16</td>
<td>0.957</td>
<td>0.179</td>
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<td>2440</td>
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</tr>
<tr>
<td>1 1/4</td>
<td>11 1/2</td>
<td>1.660</td>
<td>11/16</td>
<td>1.278</td>
<td>0.191</td>
<td>40.0</td>
<td>1950</td>
</tr>
<tr>
<td>1 1/2</td>
<td>11 1/2</td>
<td>1.990</td>
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<td>1.500</td>
<td>0.200</td>
<td>55.0</td>
<td>1740</td>
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<tr>
<td>2</td>
<td>11 1/2</td>
<td>2.375</td>
<td>3/4</td>
<td>1.939</td>
<td>0.218</td>
<td>92.0</td>
<td>1590</td>
</tr>
</tbody>
</table>

USE SCHEDULE 80

<table>
<thead>
<tr>
<th>I.D. (in.)</th>
<th>Nominal Wall Thickness</th>
<th>g/min at 10 ft/sec velocity</th>
<th>Allowable Working Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.815</td>
<td>0.250</td>
<td>16.3</td>
<td>3880</td>
</tr>
<tr>
<td>1.160</td>
<td>0.250</td>
<td>32.9</td>
<td>2880</td>
</tr>
<tr>
<td>1.338</td>
<td>0.281</td>
<td>43.8</td>
<td>2860</td>
</tr>
<tr>
<td>1.689</td>
<td>0.343</td>
<td>69.8</td>
<td>2990</td>
</tr>
</tbody>
</table>
weaknesses associated with threaded pipe.

Means must be provided for assembling and disassembling of the piping by means of hand tools. The standard methods are using forged steel unions and flanges. The unions have steel to steel seats with spherical to angle mating surfaces to provide positive seating. The nut is tightened to increase the tension of the thread.

The second method for assembling the piping system is to use flanges. This method has gained wide acceptance. The pipe is threaded or welded to the flanges, which are held together by two of four bolts. The flanges are sealed with O rings. Older equipment used copper, aluminum, leather, and synthetic seals. Flanges are made to connect pipe, but not to correct misalignment. This is a serious condition which will lead to premature piping and sealing failure.

In designing hydraulic piping and tubing for molding machines it should be assumed they will be used as a stepladder, if at all possible. They should also be supported to prevent excessive vibration and corresponding joint and seal failure. Failure of piping is relatively rare. If it appears in the same place, the system should be evaluated.

**Tubing**

The tubing used in the hydraulic system of molding machines is a low carbon steel similar to grades 1010 and 1015. It is fabricated by cold drawing and annealing to give seamless tubing, or by cold working and annealing electric resistance welded steel. Steel tubing is identified by its outside diameter and its wall thickness. There are many thicknesses available. Table 6-2 shows dimensions and properties of some of the steel tubings which can be used on molding machines. The strength of the tubing is determined by its wall thicknesses, which are usually designated by Birmingham wire gauge (BWG) numbers.

It should be noted again that copper tubing is not desirable for hydraulic use. Copper promotes catalytic decomposition of oil. It also work hardens by vibration, causing failure. Galvanized steel is never used because it will react with additives to create insoluble zinc metallic soaps that will cause malfunctioning.

Tubing is selected because of good flow characteristics (the usual velocity of oil in the tube is between 10 to 15 ft/sec) and strength. One of the superior characteristics of tubing is that it can be bent, permitting fewer fittings in the system. Since a fitting is costly in terms of material and labor, and a source of leakage and maintenance, this is a significant advantage. In addition, properly bent tubing will keep turbulence to a minimum and increase the efficiency of the system. Bench type tube benders which can handle tubing through 1 in. O.D. should be available in the plant. The radius of bending is approximately 2 1/2 to 3 times the inside diameter of the tube. Larger diameter tubing can be hand bent by filling the tube with sand, sealing off both ends, heating it to cherry red heat, and bending it around pins placed on a steel plate. A properly bent tube has a maximum flattening of between 5 and 10%.

Table 6-2 also indicates the approximate recommended minimum distance
between supports for tubing. If insufficiently supported, vibration, leakage, and premature failure will occur. When oil under pressure flows around bends, it will tend to straighten the tubing. This, of course, is the principle of the Bourdon gauge. If tubing failure reoccurs at a given spot, additional support should be considered.

Unlike pipe, which is threaded, tubing is always connected by flared, flareless, or welding type fittings. Much progress has been made in recent years in the development and design of such connectors, with the result that maintenance of hydraulic tubing can be kept at a minimum. Flared fittings are rarely used on molding machines. The flareless type gives at least equivalent performance and is much simpler to install.

A flareless fitting consists of three parts; the body, a case-hardened sleeve, and a nut. The tubing is cut square, and the internal and external burrs removed. The nut is put on the tube, then the sleeve is slipped over the tube, the tube inserted into the fitting, and the nut tightened. The nut causes the heavy edge of the sleeve to shear a groove on the outer surface of the tube, making a tight joint between the fitting and the tube. The nut presses on the bevel at the rear of the sleeve, causing it to clamp tightly to the tube. When fully tight, the sleeve is bowed at the midsection and acts as a spring to maintain constant tension between the body and the nut, preventing the nut from leaking.

There are elastomeric seals using O rings, rubber bushings, or teflon rings, which provide soft seals with a cushion, preventing leakage from vibration. A sleeve is inserted over the tubing into which is placed the seal. A nut tightening the sleeve compresses the elastomeric substance causing the seal. Larger diameter tubing is usually welded into socket fittings. This has the same advantages as welding pipe. Tube connectors are available in many different configurations.

Tubing gives a small amount of flexibility to the system which helps dampen and absorb vibration. Therefore, it is desirable to use bends rather than straight tubing to enable one to maximize its vibration and leak resistant properties. Proper terminal fittings should be selected to minimize the number of bends. Maintenance of tubing almost always centers around leakage at end of the connectors.

**Hose.** The third major hydraulic transmission mechanism is the flexible reinforced rubber hose. The inner core is made of oil resistant synthetic rubber. The outer core for higher pressures is synthetic rubber, and for lower pressures can be synthetic rubber impregnated with cotton braid. Low pressure hose uses single wire braid reinforcement, medium pressure hose multiple wire braid, and high pressure multiple spiral wound wire braid. Table 6-3 gives typical dimensions and properties of flexible rubber hose used on injection molding machines.

Rubber hose is usually the connection of choice between two movable parts. Examples are the movable carriage on the injection end, and hydraulic cylinders
Table 6-2  Dimensions and Properties of steel tubing

<table>
<thead>
<tr>
<th>Size</th>
<th>O. D. (in.)</th>
<th>Length of Tubing Between Supports (ft)</th>
<th>Wall Thickness</th>
<th>I. D.</th>
<th>g/min 10 ft/sec velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>0.250</td>
<td>3</td>
<td>20</td>
<td>0.035</td>
<td>0.180</td>
</tr>
<tr>
<td>5/16</td>
<td>0.312</td>
<td>3</td>
<td>20</td>
<td>0.035</td>
<td>0.242</td>
</tr>
<tr>
<td>3/8</td>
<td>0.375</td>
<td>3</td>
<td>20</td>
<td>0.035</td>
<td>0.305</td>
</tr>
<tr>
<td>1/2</td>
<td>0.500</td>
<td>3</td>
<td>19</td>
<td>0.042</td>
<td>0.416</td>
</tr>
<tr>
<td>5/8</td>
<td>0.625</td>
<td>4</td>
<td>18</td>
<td>0.049</td>
<td>0.527</td>
</tr>
<tr>
<td>3/4</td>
<td>0.750</td>
<td>4</td>
<td>16</td>
<td>0.065</td>
<td>0.620</td>
</tr>
<tr>
<td>7/8</td>
<td>0.875</td>
<td>4</td>
<td>15</td>
<td>0.072</td>
<td>0.731</td>
</tr>
<tr>
<td>1</td>
<td>1.000</td>
<td>5</td>
<td>13</td>
<td>0.095</td>
<td>0.810</td>
</tr>
<tr>
<td>11/4</td>
<td>1.250</td>
<td>7</td>
<td>12</td>
<td>0.109</td>
<td>1.032</td>
</tr>
<tr>
<td>11/2</td>
<td>1.500</td>
<td>7</td>
<td>11</td>
<td>0.120</td>
<td>1.260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size</th>
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<th>Length of Tubing Between Supports (ft)</th>
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<tbody>
<tr>
<td>1</td>
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<td>11/4</td>
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<td>0.109</td>
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<td>11/2</td>
<td>1.500</td>
<td>7</td>
<td>11</td>
<td>0.120</td>
<td>1.260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thread Description for Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/16 X 20 UNF</td>
</tr>
<tr>
<td>1/2 X 20 UNF</td>
</tr>
<tr>
<td>9/16 X 18 UNF</td>
</tr>
<tr>
<td>3/4 X 16 UNF</td>
</tr>
<tr>
<td>7/8 X 14 UNF</td>
</tr>
<tr>
<td>1-1/16 X 12 UN</td>
</tr>
<tr>
<td>1-3/16 X 12 UN</td>
</tr>
<tr>
<td>1-5/16 X 12 UN</td>
</tr>
<tr>
<td>1-5/8 X 12 N</td>
</tr>
<tr>
<td>1-7/8 X 12 N</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>0.188</td>
</tr>
<tr>
<td>0.250</td>
</tr>
<tr>
<td>0.313</td>
</tr>
<tr>
<td>0.406</td>
</tr>
<tr>
<td>0.500</td>
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<tr>
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<td>0.750</td>
</tr>
<tr>
<td>1.125</td>
</tr>
<tr>
<td>1.375</td>
</tr>
<tr>
<td>1.813</td>
</tr>
<tr>
<td>2.375</td>
</tr>
</tbody>
</table>
attached to molds. Hose is easier to install than permanent connections, and because of its ability to expand slightly with pressure, it exerts an accumulator action which helps dampen pressure surges and vibration in the system. Hose and fittings come in many shapes and configurations. They are either permanently assembled or reusable. The reusable ends have the advantage of being able to be fabricated in the plant. This significantly reduces the stock of hose assemblies that would be required. The disadvantage is the possibility of poor workmanship leading to failure.

When hose is installed, there should be no twisting or torsion at any time during installation or service. The full minimum radius requirements should be met. When the hose is used between two points in a straight line, enough slack should be left to allow for the bending radius. Hosing will change in length when pressurized, and the slack compensates for this change. Elbows are very useful in designing for flexible hose. Hoses should be kept free so that there is no abrasive action on the outside. They should be away from hot parts, such as heating cylinders. Hose manufacturers have manuals for installation which should be consulted.

Maintenance of Connectors

Maintenance of hydraulic fluid power connectors is almost always repairing leakage around the connectors and their joints. It is important to have records which will indicate the frequency of occurrences of failure at each location. A leak at the rate of one drop per second on a three shift, 6 day basis, loses approximately 350 gal of oil per year. The cost of reclaiming oil, its loss of properties, the labor in refilling machines, and the gathering up of spilled oil should be held to a minimum.

Not the least disadvantage of a leaking machine is the possibility of the oil level falling below operating requirements, without detection, causing damage to the equipment. A leaky machine (and the consequent dirt around it) does not make for good housekeeping and clean work. In those applications where vacuum metallizing, spraying, and painting are to be post molding operations, oil is a major hazard. Obviously, spilled oil increases the potential for fire.

The common causes of leaks in connectors and their fittings on molding machines follow:

1. Mechanical vibration and stress.
2. Improper selection of the connector.
3. Improper installation of the connector.

*Leak Prevention.* A method of maintenance to prevent leakage will include the following:
1. Clear management policies stating that leakage is not desirable.
2. A maintenance reporting schedule that would allow identification of the offending units.
3. A complete supply of necessary piping, tubing, hoses, and fittings to meet maintenance problems as they occur. A good portion of improper maintenance is due to emergency and make-shift repairs because parts were not available. These tend to remain permanently.
4. Adequate machinery for fabricating tubing, piping, and rubber hose.
5. A continuing evaluation of new methods of connecting.
6. A continuing review of the hydraulic breakdowns and their solutions.

Water Hammer; What Is It and How To Avoid It

When there is a sudden change of velocity, in a fluid moving in a closed container, such as when there is a rapid shifting of valves, a phenomenon occurs called water hammer. The kinetic energy of the moving oil is converted suddenly into pressure energy. This pressure energy coupled with the inertial effect of the oil behind it causes a sudden surge of pressure in the pipe. This can result in pressures as much as 1000 psi higher than encountered in the normal operation of the system. It will expand the pipe and travel to the end. The shock wave will vibrate back and forth, with a clanking and banging noise, until its energy is dissipated by friction. Sometimes the noise is obscured by the normal noise level of the machine. The expansion of the walls of the pipe will cause a shortening in its length, thus putting a strain on the welds and connectors. One of the causes of water hammer can be traced to dirty oil.

Dirty oil can cause valve spindles to hold tight, requiring a much greater than normal pressure to move them. When the spindle starts to move, it clears itself and jumps rapidly, shifting the direction of flow. Water hammer effect can be eliminated by the following techniques:

1. Keep the velocity of the fluid low.
2. Slow down the valve closing speed either by built-in chokes or by the use of surge-damping valves which allow controlled, gradual acceleration of flow in one direction and free flow in the other direction.
3. Add a damper accumulator to the system.
4. Clean or replace dirty oil.

PACKING AND SEALS

Hydraulic machinery would not be possible without seals and packing (7). The requirement of 100% reliability in aircraft and the space program has led to major improvements in this area. The plastics engineer should be alert to the
possibility of modifying existing conditions to utilize these improvements.

The three systems which use packing and seals in the plant are the hydraulic, pneumatic, and water. Each has different requirements, although the engineering principles are the same.

There are two types of seals — the static seal and the dynamic seal. The static seal is used to prevent the leakage of liquids and gases between parts that are not moving. Gaskets are examples of static seals. The term "gasket" is usually used in referring to sealing of flat plates and surfaces, such as covers on an hydraulic tank. Materials used for flat gasketing are vegetable fiber sheets, synthetic rubber, duck, and asbestos. The second type of static seal is used where diametral clearances are involved, such as sealing a stationary pin in a hole or a valve seat. The O rings which make superior gaskets are used for these applications.

A dynamic seal is a seal of liquid or gas between two members which are moving with respect to one another. There is a reciprocating type seal where the motion is reciprocal, such as in a piston in a cylinder, and the rotary type of seal where the motion is rotary, such as the shaft of a pump or occasionally a combination of the two.

Packing can also be classified in terms of shape. Six major types found in molding plants follow:

1. The V-type packing, used on the injection and clamping cylinders to seal between the piston and the housing.
2. The U-type packing, used as pneumatic and certain low-pressure hydraulic applications.
3. Cup packing, primarily used in air cylinders and air applications.
4. Flange packing, used in low-pressure applications as a shaft seal and also for a wiper.
5. Metallic piston rings, used on the injection and clamping rams and smaller hydraulic cylinders.
6. The O rings, used in almost all components and applications.

The materials that are used in packings and seals are numerous, with the main ones as follows:

1. Metal (copper, steel, stainless steel, bronze, and iron).
2. Natural and synthetic rubber.
3. Fluorocarbon plastics.
4. Asbestos.
5. Cloth impregnated with synthetic rubber.
6. Leather impregnated with wax or synthetic rubber.

The two classes of packing most widely used in molding are the fabricated and the homogeneous rubber-type packings. The fabricated packings use various cloth or asbestos and impregnate them with one of the many types of synthetic
rubber or polymers. Their main use is in the V rings which seal the reciprocating plungers on the clamp and injection ram. The homogeneous packings are synthetic rubber. Their main use is in cups and 0 rings.

Fabricated packings require less tolerances, and lower concentricity requirements. They can be used with more metals. For example, cast iron (used for many rams) is only usable with fabricated packings. They will take high pressures up to 10,000 psi without excessive leakage or wear. This is well above the required operative range for molding machines. Fabricated V rings can be cut for easy installation while the homogeneous variety cannot.

The homogeneous type of packing is elastomeric by nature. The essential requirements of a dynamic seal is a surface finish finer than 16 microinches rms. Pistons should be hardened, tolerances held, and excentricity at a minimum. Homogeneous packing will take temperatures up to 300°F, and maximum pressures to 5000 psi in dynamic applications with the use of antiextrusion devices. In static homogeneous seals pressures can exceed 20,000 psi.

V-Type Packing

The V-type packing (Figure 6-7) consists of three parts — the male adapter (which is placed in the packing gland opening first, with the flat side down); V-rings (the number determined by the pressure, and the cylinder and plunger diameters); and the female adapter (which is the last packing to go in and on which the packing gland seats).

The principle of the packing is that the pressure of the fluid forces the V-ring apart, forming the seal. The higher the pressure of the fluid, the tighter the packing seals against the plunger. At zero and low pressure the seal is kept because the cross section of the V-ring is slightly larger than the packing box, causing a slight compression of the packing. It is desirable, when possible, to preload the packing by means of either a conical spring or individual springs spaced on the packing. When refacing or replacing pistons care should be taken to maintain the slight compression, if not there will be leaks under low pressure. Overtightening this packing will not increase the sealing. On the contrary, excessive pressure will cause rapid wear and deterioration.

In fabricating packing, the cuts should be staggered at 90 and 180° intervals. They are usually prelubricated with graphite making for easier inserting. If there is any difficulty, particularly on larger glands, soaking the packing in oil or generously lubricating the packing box will help. Machine oil pressure can be used to remove the packing.

In applications where pressure exists in both directions, such as on a cylinder piston, two sets of the packing can be installed, with the V's facing each other. They must be separated by a metal separator firmly attached to the piston, or the pressures will be transmitted to each other, nullifying the effect of the packing. This type seal has very low leakage, good wear and has found increasing application.
Installation details for fabric reinforced V-rings

Figure 6-7  Installation details for fabric reinforced V-rings (Crane Packing Company).

U-Rings

The U-ring packings (so called because the cross sections resemble the shape of a U) works on a similar principle to V-packings; the pressure causes the packing to expand and hug the shaft. The pressure of the seal is proportional to the pressure of the fluid. Homogeneous U-rings have low frictional characteristics and are used with pressures up to 3000 psi. They are single installations and are never stacked. A popular use of U-rings is on the piston of an air cylinder. On new equipment U-rings have been largely supplanted by V-rings or O-rings.

Cup Packing

Cup packings are widely used on the ends of pistons in pneumatic applications. Fabricated and rubber impregnated leather cups are used. The homogeneous type is not often found since other packings are less critical and perform equally
well. The cup packing is usually mounted by means of a boss with a metal to metal tightening seal. This centers the cup and prevents excessive tightening of the packing.

**Metallic Piston Rings**

Metallic piston rings of the hydraulic-step type are used extensively on the injection and clamping cylinders for the internal piston seal, where they have the tremendous advantage of reliability and long trouble free life. The leakage past a series of piston rings is remarkably low and can be readily tolerated in molding machines. It has been found that the sealing is done by the first one or two rings. The additional rings increase the service life of the seal and guard against maladjustments or malfunctioning of a single ring.

Malfunctioning of piston rings will cause a hot spot to develop on the cylinder wall where the oil rushes by. It is also suspect when the cylinder moves toward the rod end when pressure is applied to both ends. If the occasion arises for replacing piston rings or reinserting plungers with piston rings on them, it is well to obtain standard automobile type piston ring contractors. If not available, thin spring steel or shim stock can be wrapped around the piston rings and held tightly while the assembly is inserted.

**0-Rings**

One of the great technological breakthroughs in sealing and packing was the discovery of the elastomeric, homogeneous 0-ring (Figure 6-8). This, coupled with synthetic rubber, and the new material discoveries that came after World War II, has led to a versatile, useful, simple, long lasting, inexpensive type of seal. While the 0-ring will not solve every packing and sealing problem, its intelligent use is a great help in the injection molding field. For static applications, the 0-ring seal can hold all pressures that will be encountered in the molding machines. In dynamic applications, seals of 5000 psi are obtainable with the proper antiextrusion devices. The seals can be placed either in a groove in the piston or cylinder wall. The preferred location is on the piston, because it is easier to machine the groove there than in the cylinder. They are very easily maintained and replaced, are readily available, and have small space requirements. The seal can usually be reused when taken apart for inspection.

The retaining grooves for 0-rings are very economical to make and do not require any packing glands or other paraphernalia associated with some packing types. They can be installed quickly and with no special tools on both regular and irregular parts. However, they do have definite limitations, such as in high speed reciprocal and rotary actions the tendency to spiral and roll, the requirements for close tolerances and clearances in the mating parts, and like all homogeneous packings the requirement of a fine finish on the moving parts.
Spiral failure can be reduced by using an X shaped O-ring which fits in the same packing gland as a standard O-ring.

The O-rings are made of many synthetic rubber compounds. When used on
plastics care should be taken to see that they are compatible. The O-ring seals because the fluid pressure forces the precompressed O-ring in the direction of the flow. The pressure of the fluid squeezes the O-ring either against the piston and the cylinder in dynamic applications or the mating surfaces in static applications. When the pressure is reversed the O-ring moves in the other direction with the same results. When the pressure is too high or the clearance too low, the condition of extrusion occurs and causes rapid seal failure. To overcome this, leather backup rings are installed for pressures of 1500 psi and over. A durometer hardness of 70 is recommended for pressures to 1500 psi; 80 durometer to 2500 psi; and 90 durometer, for higher pressures. The extra hardness acts to limit the extrusion of the seal.

The O-rings can be used in noncircular sealing providing there is a minimum radius for bending. Square, rectangular, and irregular grooves can be machined. The O-rings of the proper circumference can be inserted and a very effective seal had. This is particularly useful in mold cooling applications. Premachined plates with O-rings attached are commercially available.

Manufacturers of O-rings have excellent manuals describing the applications and engineering properties of their product. These are readily available and it is strongly recommended they be obtained and read.

**Maintenance of Packing and Seals**

Maintenance of packing and seals does not present any difficulty. Packing failure, aside from normal wear, is most often caused by scoring on the plunger. If this is the case, the plunger should be either welded or brazed and then resurfaced. When packing consistently gives trouble, the system in point should be examined to see if there is extensive wear, whether the cylinder I.D. is out of round and whether the packing is acting as a bearing instead of just a packing. Dirty hydraulic fluid is a cause of packing failure. The decomposition products get on the moving pistons and initiate scoring. Once this starts, leakage increases rapidly. At the first sign of scoring, the machine should be stopped and the cause of the trouble found and rectified.

At least one spare should be in stock for every packing used in the plant. Invariably a cost of a repair is greater than the cost of the packing. If new packing is available, maintenance men will change it depending on conditions rather than availability.

To summarize, the major factors that cause packing failure follow:

1. Improper original design.
2. Wrong clearance.
3. Improper support.
4. Wrong metal on sealing parts.
5. Improper finish on metal surfaces.
6. Overheating of system.
7. Contaminated hydraulic fluids.
8. Improper lubrication.

FLUID POWER CALCULATIONS

The following formulae are useful for calculating connector sizes, volume, speed, and time in various parts of the hydraulic system.

\[
R = \frac{7740UD}{\nu} = \frac{3160Q}{\nu D}
\]  (6-3)

where

\( R \) = Reynold's number
\( U \) = velocity (ft/sec)
\( D \) = inside diameter (in.)
\( Q \) = flow rate (gal/min)
\( \nu \) = kinematic viscosity (cSt).

\[
\Delta P = \frac{0.0808 f L U^2 S}{D}
\]  (6-4)

\( \Delta P \) = pressure loss (psi)
\( f \) = friction factor
\( L \) = length (in.)
\( U \) = velocity (ft/sec)
\( S \) = specific gravity
\( D \) = inside diameter (in.)

\[
f_{\text{laminar}} = \frac{64}{R}
\]

\[
f_{\text{turbulent}} = \frac{0.316}{R^{0.25}}
\]

\( R \) = Reynold's number

**Flow rate in circular tubes**

\[
Q = 2.45 D^2 U
\]  (6-5)

where

\( Q \) = flow rate (gal/min)
\( D \) = inside diameter (in.)
\( U \) = velocity (ft/sec).
The volume of oil to move a cylinder is

\[
\begin{align*}
\text{Back end} & & \text{Rod end} \\
V &= 0.785 \, D^2_c \, L & V &= 0.785 \, (D^2_c - D^2_R) \, L
\end{align*}
\]  
(6-6)

where \( V \) = volume (in\(^3\))  
\( D_c \) = diameter cylinder (in.)  
\( D_e \) = diameter rod (in.)  
\( L \) = length (stroke) (in.)

The cylinder speed is

\[
\begin{align*}
\text{Back end} & & \text{Rod end} \\
U &= \frac{Q}{D^2_c} & U &= \frac{1.273Q}{(D^2_c - D^2_R)}
\end{align*}
\]  
(6-7)

where \( U \) = speed (in./min)  
\( Q \) = flow rate (in\(^3\)/min)  
\( D_c \) = diameter cylinder (in.)  
\( D_R \) = diameter rod (in.)

\[
\begin{align*}
\text{Back end} & & \text{Rod end} \\
Q &= \frac{UD^2_c}{294} & Q &= \frac{U(D^2_c - D^2_R)}{294}
\end{align*}
\]  
(6-8)

where \( Q \) = flow rate (gal/min)  
\( U \) = speed (in./min)  
\( D_c \) = diameter cylinder (in.)  
\( D_R \) = diameter rod (in.)

The time to move the cylinder is

\[
\begin{align*}
\text{Back end} & & \text{Rod end} \\
T &= \frac{0.204 \, D^2_c \, L}{Q} & T &= \frac{0.204 \, (D^2_c - D^2_R) \, L}{Q}
\end{align*}
\]  
(6-9)

where \( T \) = time (sec)  
\( L \) = length stroke (in.)  
\( Q \) = flow rate (gal/min)  
\( D_c \) = diameter cylinder (in.)  
\( D_R \) = diameter rod (in.)
It is best to design for laminar flow (Reynolds number below 2000). To accomplish this larger connectors, fittings, and valves are required than if turbulent flow occurred. The result is often a compromise between cost and optimum design. It is interesting to note that the friction factor for \( R \) (Reynolds number) 2000 (laminar flow) is 0.032 (eq. 6-4). At \( R \) equal 4000, it is 0.040, at \( R \) 8900 0.032. Above this value the friction factor is lower than the lowest found among laminar flow conditions. There are other factors, which cause problems aside from turbulent flow.

One of these is the velocity of the oil. If it is too high there are significant pressure drops in the system (eq. 6-4). When rapidly moving oil is stopped surge pressures occur. In extreme cases they cause "water hammer." It has been estimated that rapidly stopped oil generates a surge pressure of approximately 40 psi per ft/sec of velocity. Velocities that are too low increase the cost of valving and piping. The maximum velocity generally recommended is 15 ft/sec. Higher velocities in certain parts of the equipment can be found.

To illustrate the use of these formulae let us suppose the following condition. An hydraulically activated cam has to be returned to its position in one second to prevent interference with the mold closing. It is activated by a 3 in. cylinder with a 10 in. stroke. The oil has a specific gravity of 0.85 and a viscosity at the operating temperature of 300 SUS. The problem is to determine the hydraulic and piping requirements.

From (6-9) we can determine the flow rate needed.

\[
1 = \frac{0.204 (3)^2 (10)}{Q}
\]

\[
Q = 18.4 \text{ gal/min}
\]

To determine the size connector for laminar flow we must find the Reynolds number. From (6-2) we can determine the kinematic viscosity.

\[
v = 0.220 (300) - \frac{135}{300}
\]

\[
v = 65 \text{ cSt}
\]

From (6-3) we can determine the diameter of the pipe for laminar flow with a Reynolds number of 2000.

\[
2000 = \frac{(3160)(18.4)}{65D}
\]

\[
D = 0.45 \text{ or } \frac{1}{2} \text{ in. I.D. connector}
\]

The diameter of the connector calculates to 0.45 in.. A 1/2 in. connector would be used.

The pressure loss can now be calculated. Equation 6-5 will give the velocity.
18.4 = (2.45)(0.5)^2 U

U = 30 ft/sec

Even though this velocity is high it is acceptable in this part of the circuit. If it were not, the diameter of the connector would have to be increased. The friction factor is obtained from (6-4).

\[ f = \frac{64}{2000} = 0.032 \]

The pressure loss is calculated from (6-4)

\[ \Delta P = \frac{(0.0808(0.032)(10)(30)^2(0.85)}{0.5} \]

\[ \Delta P = 39 \text{ psi} \]

The pressure loss is 39 lb psi, which is acceptable for this application.

If 18.4 gal/min were not available at that time in the cycle, a smaller source could be used in conjunction with an accumulator. The accumulator can be charged at a much lower rate so that smaller diameter hose could be used from the pressure source to the accumulator. The connection from the accumulator to the cylinder would still be 1/2 in., though much shorter in length. An accumulator circuit is shown in Figure 6-29.

HYDRAULIC VALVES

Three types of valves are used in hydraulic systems. Directional control valves change or control the direction of the flow of oil. Examples are two way, four way, and check valves. Pressure control valves control the pressure in the system. The consist of relief, unloading, pressure reducing, sequence, and counter balance valves. The third type is flow control valves which control the amount of flow.

Two Way Valves

The simplest directional control valve is a two way valve. It is either open or closed permitting or stopping oil flow. Figure 6-9 shows a schematic diagram of a normally open, manually controlled two way valve. Housing of directional control valves are usually an iron or steel casting with a hole machined through. The ports are drilled and tapped or adapted for flanges. The end plates are held in with screws and sealed with O rings (figure 6-10). The spool or spindle is a
Figure 6-9 Schematic representation of two way, spring returned, manually operated, normally open valve with symbol.

turned piece of hardened, ground steel. A second type of construction, where size and weight considerations are important, uses a hollowed-out spool with radial holes drilled for proper flow paths for the valve's function. In this particular valve (Figure 6-9) a spring is used to maintain the valve in its normal, or open position. When the manual side is pushed, the spool shifts over, compressing the spring. A drain is provided to remove the oil from behind the spool caused by leakage between the spool and the housing. Without it, it would be difficult and perhaps impossible to move the spool. When the spool is shifted, the land of the spool covers the inlet opening. When the manual force holding the spool is released, the spring will push the spool back to its original position, opening the valve. A hole drilled the length of the spool and exiting at right
Figure 6-10 Four-way valve showing machined plunger and cored body (The Oilgear Company).
angles at the front end of the spool acts as the drain for the other side of the valve. Beneath the valve is its JIC symbol. It is always shown so that when the spring is activated, the valve will assume the configuration shown in the box adjacent to the symbol. The following are the most common methods of activating valves:

Spring.
Manual.
Push-button
Lever.
Pedal or treadle.
Mechanical.
Solenoid.
Reversing motor.
Pilot pressure (supplying or releasing).
Pilot pressure, differential.
Solenoid pilot.
Thermal.
Servo.
Detent.
Pressure compensated.

There may be combinations of actuators such as hydraulic or manual, solenoid or pilot, and such. In this example, when the spring is activated (the normal position), the valve is open. When the manual is operated, the valve closes. If there were no spring in the valve and a manual control was used on both sides, both sides would have the “manual” symbol.

Some of the major uses for two way valves in injection molding are in deceleration circuits, pump separation circuits, the selection of different hydraulic pressures, the selection of different hydraulic speeds, and in prefill circuits. Figures 6-11 and 6-12 illustrate some of these applications. The others will be subsequently illustrated.

**Deceleration Circuits.** Figure 6-11 shows a deceleration circuit which will bring a cylinder to a smooth stop. Speed control is important in injection molding. Because of the high inertia of the heavy platens and molds a severe jarring can occur with rapid opening at the end of the stroke. Since many knockouts are activated by the return action of the ram, slow down is required for their smooth operation. A circuit like this is useful too, for hydraulically operated cams. The clamp cylinder is operated by the four way directional control valve. In its center position all ports are blocked. When the forward solenoid \( F \) is energized the valve shifts so that the pressure is ported to the rear of the clamp cylinder and the tank connection to the front. Even though the two-way valve is energized (open) (because the
Figure 6-11 Deceleration circuit to bring cylinder to a smooth stop using a two-way valve.

cam has depressed the roller) both sides are connected to pressure, thus not affecting the forward motion. The clamp cylinder now moves forward, releasing the mechanical plunger of the two way valve. For return, solenoid R is energized. This send pressure to port B and port A to tank. The cylinder begins to retract. When the cam hits the plunger of the two way valve it starts to shift it to the open position. Since port A is connected to tank it will start to bypass the pump pressure to tank. This will slow the ram down to a gentle stop. The four way valve is now shifted to its neutral position so that port A is blocked and the pressure of the system will no longer go to tank. While this is a simple way to decelerate, it is good in only one direction at a time and is difficult to adjust.

Figure 6-12 shows an improved deceleration circuit. The circuit consists of a limit switch (LS-1) which controls a two-way valve used for speed control (No. 1) and therefore a flow control valve (No. 1). They are attached to the
Figure 6-12 Uses of two and three way valves.

pressure inlet before the directional control valve. The speed control valve is normally open. As long as LS-1 is not contacted the flow in the system will be maintained as such and the clamp cylinder will move accordingly. (All other elements of the circuit not pertaining to the use of two way valves have been omitted for clarity.) When LS-1 is contacted the solenoid controlled, pilot operated speed control valve No. 1 is activated, closing the valve and forcing the oil to go through the flow control valve No. 1. The speed of the cylinder will depend upon the setting of this valve. This will happen at any
time when the cam activates LS-1. Therefore speed control is available at any
time of the forward or return stroke of the clamp ram, whenever the cam hits
the switch. Should slow-down be desired in only one direction, a one way dog
type of arm can be used on the limit switch. Otherwise the limit switch can
be taken out of the circuit by means of relays or timers. Different speeds can
be had by adding an identical control circuit (No. 2). As many can be added
as required. Another way of accomplishing the same thing would be to use a
pilot operated flow control valve which would be placed into or removed
from the circuit by another two way valve.

**Holding Pumps.** In most hydraulic and many toggle operated presses a
high pressure-low volume holding pump is used to maintain the pressure in the
clamp system while the injection and cooling take place. The output of the
pump should be slightly more than enough to overcome the internal leakage
of the system. It is necessary to isolate the clamping circuit at that time, from
the injection end. An excellent way to do it is by an hydraulically piloted two
way valve (bottom of Figure 6-12). When the clamping pressure is below 400
psi, all pumps in the system are used to move the clamp. As soon as resistance
is met the pressure begins to build. When it reaches the valve setting (in this
instance 400 psi) it will shift the spool of the valve, closing it and isolating
the main pump circuits, which can be used for the injection circuits. When the
four way directional control valve shifts to open the clamp cylinder pressure
will drop until resistance is met when the cylinder opens up. The pressure will
drop below 400 psi and open the pump separation valve and permit all pumps
to move the clamp cylinder back rapidly.

**Safety.** Safety is important in a molding machine. The two way valve
illustrated in the top of Figure 6-12 is used as an hydraulic interlock. Its
normal position prevents oil from the four way valve reaching the clamp
forward position. To activate the safety valve two things are required; (a) the
safety gate must mechanically depress the valve and (b) pilot pressure must be
available. Pilot pressure is initiated by energizing the four way directional
control valve, which must be done through the electrical safety. Without pilot
pressure in the four-way valve there is no possibility of a malfunctioning of any
part of the clamp circuit. The cycle, therefore, cannot start unless the pilot
pressure is available.

**Three Way Valves**

A three way valve is one where the outlet can be connected either to pressure
or to tank. Its three main uses are for pressure readouts, safety circuits, and
activating spring returned cylinders. Figure 6-12 shows a three way valve used
for reading pressure. The normal (spring controlled) position has the pressure
port blocked and the gauge ported to tank. When the button is pushed, the
Figure 6-13. (a) Hydraulically operated, three position, spring centered, four way valve in **neutral** or **central** position. All ports are blocked. (b) Pilot pressure is applied at port 1, port 2 goes to tank. Pressure port (P) of the main valve is connected to port A and tank port (T) is connected to port B. (c) Pilot pressure is applied to port 2, port 1 goes to tank. Pressure port (P) is connected to port B and tank port to A.
gauge is attached to the pressure system. This prevents the gauge from being attached to the system at all times. There are times when the same hydraulic line will have different pressures, such as the back pressure on a reciprocating screw. Then it is desirable to use a low range gauge for accuracy instead of one which will read maximum pump pressure. This type circuit makes it possible.

If in the previous illustration, the clamp forward connection was attached where the gauge is, no oil would reach it in the normal spring position. If the activator was a mechanical cam moved by the safety gate, it would serve as an hydraulic safety.

If the clamp forward port of a spring returned cylinder was attached to the gauge port, nothing would happen until the valve was activated. Then pressure would force the cylinder forward. When the activator was removed, the clamp forward port would go to tank and the spring would retract the cylinder.

Four Way Valves

Four way directional control valves, as the name implies, have four ports: pressure, tank, and two working ports A and B. Their main use is to extend and retract cylinders; to start, stop, and reverse the direction of hydraulic motors; and to sequence machine operations.

Hydraulic cylinders used on molding machines consist of a housing with a cylindrical bore in which is placed a piston or ram. The piston has a shaft on one side which is connected to the platen or member to be moved. The large diameter end of the piston is put into the cylindrical hole and that side is sealed. The smaller diameter piston shaft extends outward through V shaped hydraulic packing which prevents leakage (Figure 6-7). It is supported by a bushing. When oil under pressure is applied to the large or head end, and the piston end is vented to tank, the piston will move forward. When the pressure is reversed and applied to the shaft side the head end is vented to tank, the piston will return. To accomplish this, a four way valve is used to direct the flow of oil (Figure 6-13). The valve, has three positions, though a two position valve will also reverse the direction. Figure 6-13A shows the spool in the central or neutral position held there by springs which are not shown. This spool configuration has all ports blocked in the central position, hence is called a closed center valve. The valve is hydraulically operated. If oil under pressure is applied to port 1 and port 2 is directed to tank, the spool will shift to the right (Figure 6-13B). The pressure port is now connected to A and B to the tank. If the pilot pressure is reversed with pressure at port 2, and 1 going to tank, the spool will shift to the left (Figure 6-13C), allowing the pressure to go to B and A to tank.

Assume a different spool configuration so that the area presented to the
pilot pressure at port 1 was larger than the area presented to the pilot pressure at port 2. If oil at the same pressure were applied to both sides the larger area at port 1 would cause the valve to shift to the right. If port 1 was ported to tank, the pressure at port 2 would then shift the valve to the left. This is called a differential operated valve.

Other Configurations. The valve in Figure 6-13 which blocks all ports in the central position must be used with accumulators. It will hold the cylinder or fluid motor in a stopped position and close the pressure and tank ports. It can be used in parallel with other circuits. A second possible configuration is the open-center type, where all four ports are connected together and hence to tank. This permits the cylinder and hydraulic motor to move. More important it unloads the pump from the pressure port to tank. This type configuration can be used to unload the pump while the safety gate is open or cylinders are at rest. Another configuration is with the pressure port blocked and A and B connected to tank. This drains both sides of the cylinder and the hydraulic motor. It can be used with other closed center valves. It is almost invariably used as the pilot operator of a four way valve. A fourth configuration blocks the tank port and attaches A and B to pressure. When moving a single acting cylinder it will act as a regenerative circuit permitting oil to go from the rod end to the back end without going through the pump. This gives fast cylinder speed. The tandem center blocks A and B and connects pressure to tank. It will lock a cylinder and a motor when the valve centers. The pressure flows through the center valve and can be directed to additional tandem centered valves. Other configurations are blocking port A and connecting port B, pressure and tank; and blocking port B and connecting A, pressure and tank.

Solenoid Operation. While direct solenoid operation can be satisfactory for valves up to 1 in. pipe size, contemporary hydraulic design has limited their use to a maximum size of 1/2 in.. A solenoid is an electrical device consisting of a coil with a steel rod through it. When the coil is energized, the magnetic field causes the rod to move. Since the force of a solenoid varies with the square of the voltage, solenoids should be selected so that they operate properly at 85% of the nominal voltage. Low voltage can cause sluggish solenoid operation which can cause machine malfunctions that are difficult to locate. On larger valves the solenoid is impractical as a direct drive. Instead it is used to operate a small four way valve which acts as a control for pilot pressure oil supply and provides oil to move the spindle or spool as previously described. These pilot operated, solenoid controlled, four way valves are usually built as one unit utilizing the pressure and drain connections of the large valve. They can, however, be operated at different pressures and with a completely different oil system. Figure 6-14 shows the new JIC configuration for a solenoid operated, pilot controlled, spring centered, four way, three position valve. Figure 6-14B shows the condensed symbols. In the event of an electrical failure a spring centered solenoid will return to its central position.
Figure 6-14  (a) Full JIC symbols for solenoid operated, hydraulically piloted, with internal pilot supply, spring centered three position, four way valve.  (b) condensed symbol of a.
Figure 6-15a shows a pictorial representation of the method of moving an hydraulic cylinder; b shows the same representation using JIC symbols. An electric motor drives an hydraulic pump which provides oil to a manually operated, two position, four way valve. There is a pressure control which limits the pressure of the system. As shown, the oil is pumped past the pressure relief valve, and a gauge, which shows the system's pressure, into the four way valve. It is set so that oil goes into the rod end of the cylinder forcing it back. The oil behind the piston goes through the four way valve into the tank. To reverse the direction, the four way valve is shifted into the other position. Should the oil pressure exceed the setting of the pressure relief valve, enough oil would bypass through it to tank, to lower the pressure to the predetermined setting.

Check Valves

A check valve permits unrestricted flow in one direction and is self-closing to prevent flow in the other direction. The three main types are the swing-type, ball-type, and poppet-type. They are actuated by gravity (not used in molding machines) or springs. Pilot operation is sometimes used. When the inlet and outlet ports of the check valve are in a straight line, it is called an "in-line" check valve. When the ports are at right angles (as an elbow) it is called an "angle" check valve.

**Swing Type.** The swing-type has a hinged flapper and is rarely spring loaded. Gravity closes the valve which must be installed in the correct position. It is not used on molding machines and is found primarily in low pressure water applications.

**Ball-Type.** The ball-type check valve is basically a ball with a spring behind it sealing off on a drilled inlet port. When oil comes in this direction (unrestricted flow) with more force than the spring, the ball moves off the seat and oil flows around it. When oil comes from the other direction, the spring has already sealed the ball onto the seat and the higher the pressure of the oil the tighter the seal. The ball-type, while simple and relatively inexpensive, has a number of disadvantages: (a) the design is such that it produces large turbulence and consequent pressure drop and heat; and (b) it has poor seal characteristics because the ball never reseats in exactly the same position. Ball-type checks however, are preferred with the more viscous liquids such as molten plastic, and are used (without springs) in preplasticizer systems between the injection and shooting cylinders.

To overcome the deficiencies of a ball in the hydraulic system, a poppet is used. Figure 6-16 shows a poppet-type, in-line check valve in the open position with oil flowing from the free flow port. It flows into chamber A through hole B and out the right-hand port. When oil stops flowing, the spring expands sealing the poppet on the seat. The higher the pressure from the blocked port, the
Figure 6-15  (a) A standard method of moving an hydraulic cylinder. (NAVPERS 16193). Pictorial representation. (b) Simple control of an hydraulic cylinder, as shown in using JIC symbols.
tighter the seal on the seat. The pressure required to overcome the spring tension and open the valve is called the cracking pressure. Most valves use a spring that requires 5 psi on the hydraulic oil to open it; 65 psi springs are available. They are usually used to create enough back pressure to pilot operate directional control valves. This is an inefficient method because of the loss of pumping capacity and heat generation.

**Pilot Operated Check Valve.** Because the principle of using pilot pressure is so common, we describe a pilot operated check valve. As with all valves and hydraulic mechanisms, it works on the application of “force = pressure x area.” Areas and pressures are selected to generate enough force to accomplish the purpose.

Figure 6-17 shows a cross-section of a pilot operated, right angle check valve. Spring 5 held in place by the housing exerts an upward force on piston 2 held on spool 1 by nut 3. The spring keeps the spool on seat 4. In normal operation the oil coming from the free flow port on the left will force the piston down and flow out the port on the bottom. When oil flow comes from the bottom port, the piston is initially on the seat because of the spring pressure so that the pressure of the oil will keep the valve sealed. The pilot pressure port is on the top. The drain port is on the right.

Figure 6-18 illustrates the schematic operation of this valve. In A oil is flowing from the free flow port out the blocked port. In B oil goes to the blocked port and cannot pass. Figure 6-18c shows the operation of the pilot valve. Pilot pressure is applied on top of piston 3. The force generated is enough to overcome the force of the oil coming from the blocked port. The oil will now be able to flow in either direction in the valve and will remain so as long as there is pilot pressure. To move the spool, the pilot pressure times the pilot piston area
must be greater than the spring force and the product of the valve sealing area times the maximum pressure applied from the blocked port. The rate of pilot oil flow will determine the speed of the spool movement. Particularly in directional controlled valves, a choke is used to control the spool speed to prevent shock in the system.

A main use for pilot operated check valves is in the prefill circuits of fully hydraulic clamp molding machines, which are very large and permit the back of the clamping ram to be filled by gravity or atmospheric pressure instead of going through the pumping system. These valves are used with jack rams (Figure 6-19). (A jack ram is a cylinder within the main ram.) The jack ram is much smaller in diameter and will therefore cause the main ram to move much faster with the maximum pump output than if the oil had to fill the larger volume behind the
Figure 6.18 Schematic operation of valve in Figure 6.17 (Vickers, Inc.)
main ram. When the forward solenoid \((F)\) of the directional control valve is energized, oil under pressure goes into the jack ram. The movement of the main ram will not have enough resistance to generate a 500-psi back pressure so that the pilot valve will not shift to operate the sequence valve. The forward motion of the main ram will cause the check valve to open permitting oil flow from the tank to the main ram area. The front of the ram is ported to tank. When the main ram is clamped and meets resistance the pressure builds up to 500 lb which operates the pilot valve, closes the sequence valve, and brings main pump pressure behind the main ram. The check valve will close sealing off the chamber \(A\) from the oil tank. Full pressure will be built up. When the ram is to return the directional control valve is shifted to the \(R\) position. This ports the jack ram to tank closing the pilot valve and the sequence valve. Pressure is applied to port \(R\) and to the pilot operated check valve. As the main ram moves back, the oil in chamber \(A\) returns to the tank through the check valve which is held open. There are decompression valves built into the pilot operated check valve.

**Decompression Valves.** When a mold is clamped or an injection ram moved forward the resistance build-up is gradual because of the yield of the metal machine parts, and the slight compressibility of the oil. However, when this oil thus compressed is decompressed rapidly, the same factors act in reverse and send damaging shock waves through the system or wear circuit components. The higher the system pressure, the greater the danger of decompression. To overcome this, a decompression valve is used which is a variation of a pilot
operated check valve. The tip of the pilot piston hits a small secondary check valve spool, before it hits the main check valve. This permits a very small amount of oil at a high velocity, to pass the check valve, drastically dropping the system's pressure. The pilot piston continues to move and opens the main check valve spool. In the event that this is not enough, a third decompression stage can be added.

Pressure Control Valves

If we take an in-line check valve and vent the restricted flow side to tank, we have a pressure control valve. If the area of the exposed free flow side is 1 in.² and the force of the spring is 500 lb, whenever the oil pressure on the inlet side exceeds 500 psi (500 lb × 1 in.²) the piston will move, opening the valve, and permit enough oil to flow past it to tank to reduce the system pressure to less than 500 psi. Then the force of the spring will move the piston to close the valve. Figure 6-20 shows a schematic drawing of an internally drained relief valve operating on this principle.

A valve of this kind can chatter, causing pressure fluctuations in the system. Damping arrangements and other techniques overcome this. This type valve will be fail safe, as wear will reduce the controlled pressure rather than raise it. It is very often used as a maximum pressure safety valve on pumps and in systems.

Balanced Piston-Type Valve. A balanced piston type valve overcomes most of the limitations of the spring loaded relief valve (Figure 6-21). The pressure to be controlled can be placed in either of the "out/in" ports. The bottom port goes to tank. The hollow piston 1 is held down by spring 5 sealing the tank outlet from the pressure side. There is a small hole (Y) in the piston, connecting the pressure side (Z) and the chamber above the piston (X). The oil pressure in both chambers Z and X are normally the same. Since the area of the piston on the X side is larger than the area on the Z side and assuming them both at the same pressure, the area differential will help spring 5 keep the piston seated.

Assume, for the moment, that the vent (W) is plugged. Nothing will happen until the pressure reaches the point where it exerts more force than the compressed spring 3 exerts on the poppet seal area at point 2. Then the seal at point 2 will open and oil in chamber X will flow past it through the center of the hollow piston into the tank. This reduces the pressure in chamber X (the top side of the piston) which will now be lower than the pressure in chamber Z. The piston moves up permitting oil to flow past the main seal to tank. When the oil pressure in chamber Z is low enough so that the poppet 2 reseats, the original conditions prevail, and the valve closes. Such pressure control is more gentle than the direct spring operated valve.

If the vent was connected to another poppet valve assembly, whose spring chamber behind the poppet had a direct connection to tank, the identical type
Figure 6-20   Schematic drawing. Spring loaded, internally drained relief valve.
Figure 6-21 Balanced piston type relief valve (Vickers, Inc.).
of control occurs. The only limitation is that the secondary control must be set at a lower pressure than the primary control. If not, the primary control would operate first.

**How To Vary The Pressures.** By using a number of remote control valves (which are simpler, less expensive, use smaller connectors, and are easier to install than the main valves), any number of different pressures become available. Figure 6-22 shows such a circuit. When the directional control valve is in its neutral position the main relief valve operates on the setting of the primary pilot (C). This will be the highest setting in the system. When solenoid A is energized, pilot valve A will control the pressure and when solenoid B is energized pilot valve B will control the pressure. The A and B can be set at any pressure lower than C. If the vent is connected directly to tank by energizing solenoid D, then the oil in chamber X of Figure 6-21 will be ported to tank permanently raising the piston I and dumping all the oil in the system to tank. The relief valve will now be acting as an unloading valve. This is acceptable for infrequent operation. Otherwise, because of the internal construction of the valve, it will overheat. For full scale operation unloading valves are used. This type of circuit can be used for installing several pressures and speeds in the clamp or injection circuits.

**Unloading Valves**

When the flow of a pump is not needed during the molding cycle, it is uneconomical and impractical to stop the pump from rotating. Sending the oil over relief valves is wasteful because of the heat energy lost by compressing and decompressing. An unloading valve is used. It sends the pump output to tank at close to atmospheric pressure, after a preset pressure has been reached in another part of the system which is applied to its pilot port. Unloading valves are used in accumulator circuits to unload the pump after the accumulator has been charged. They are also used to remove large volumes of oil rapidly from the head end of a cylinder when it is retracting. These valves are pilot operated, spring returned, normally closed two way valves.

Unloading valves are made with poppet type pilot operation similar to relief valves. This type of valve requires a somewhat higher pressure during unloading, which adds to the heat and horsepower loss. For this reason, most larger unloading valves are manufactured with direct spring action. An example of the use of an unloading valve in a hi-lo pump circuit is shown in Figure 6-38.

**Sequence Valves**

A sequence valve blocks the flow of oil in a secondary circuit until a set pressure is reached. The valve then opens, permitting this primary system to be connected
Figure 6-22 The use of pilot valves to get different pressures from the same main relief valve.

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to a secondary system (Figure 6-23). The secondary system pressure can vary from zero to that of the primary system before the valve opens. Therefore, the drain must be externally connected. The sequence valve, in essence, is a normally closed, spring-returned, piloted, two way valve.

The pilot is usually internal. It is connected from the primary system to the bottom part of the spool. When enough force is developed to overcome that of the spring the valve opens. It will remain open as long as the primary pressure is maintained at that or higher value. If the pilot is external it can be used as a safety interlock or to operate the valve when other conditions of the circuit are met (Figure 6-19 and 6-40). In many circuits it is desirable to have unrestricted reverse flow from the secondary to the primary port. This is done with a check valve either integrally built or externally connected.

Sequence valves are used in regenerative circuits (Figure 6-40), where a minimum pressure is required for a control circuit, and in operations where it is essential to have one part of the system pressurized before the other.

Counterbalance Valves

A counterbalance valve (foot valve, back pressure valve) has free flow in one direction (through an integral check valve) and blocked flow in the other direction, until a preset pressure is reached. Counterbalance valves are often connected to the outlet ports of vertical cylinders to counterbalance their weight. They are also used on the jack ram end of horizontal clamping cylinders to counteract the inertia of the platen and cylinder and prevent lunging or slamming of the piston. They provide the resistance for the screw while plasticizing and are commonly known in that capacity as the back pressure valve.

Figure 6-24 shows a schematic of a counterbalance valve with oil flowing past the check valve in the free flow direction. When oil comes from the restricted flow port, nothing will happen until there is enough force generated under the piston to counterbalance the spring. The valve will then open and remain open as long as that minimum pressure is maintained.

Pressure Switches

A pressure switch will activate an electrical switch when the pressure rises (or falls) to a preset value. These switches are used on molding machines to initiate the injection forward cycle when the clamp pressure has been built up. At the same time, they can start the overall cycle timing. They are used in accumulator circuits for controlling the accumulator pressure. They are used for sequence control, initiating an action when the pressure indicates a previous action has been completed.

The simplest type consists of a piston with one side exposed to pressure and the other side spring loaded. The piston depresses an electrical switch whose
Figure 6-23 Sequence valve. When pressure in primary system reaches control point, plunger moves upward, connecting primary and secondary systems.
Figure 6-24 Counterbalance or foot valve which maintains a back pressure in one direction and free flow in the other direction.
position can be varied to adjust the pressure. A second type has a poppet valve which, after unseating, allows pressure to go into a chamber in which the actuating piston is located. An integral check valve holds the oil in the control chamber. The valve cannot be reset until the pressure is reduced to the check valve setting, approximately 25 psi. If instead of the check valve a small orifice is used to drain the control chamber to tank, the size of the orifice will control the time to reset. This can be used as a timer, from milliseconds to 5 sec. Its accuracy depends on the viscosity of the oil.

A Bourdon tube may be used to actuate a pressure switch adjustable to rising and falling pressures. The tube, which uses the same principle as a Bourdon type pressure gauge, tends to straighten out with increasing pressure. This motion can be used to actuate a number of different switches.

**Pressure Reducing Valves**

It is often necessary to have a secondary reduced pressure. This might be used for running hydraulic cylinders for cams, knockouts, or hydraulic motors. There are two types of valves. One maintains a constant pressure differential between the outlet and inlet pressures. If the pressure differential is 500 psi, and the input pressure is 1800 psi the valve will put out oil at 1300 psi. If the input pressure drops to 1500 psi the output pressure will drop to 1000 psi.

The second type (Figure 6-25) will maintain a constant output pressure regardless of the input pressure. The valve consists of a pilot assembly, containing poppet 1 and adjustable spring 2. Spool 4 has spring 5 which maintains it in the open position. The top and bottom of the spools, which have the same areas, are connected together through an orifice ($E$).

When the pressure at the inlet port does not exceed the pressure setting, spring 5 keeps the valve open because the pressures in chamber $F$ and under the spool are the same. The outlet pressure is connected through channel $D$ through the spool to chamber $F$. As the pressure builds up in the outlet port, it is transmitted to chamber $F$. When the pressure reaches the spring setting of the poppet valve, it will unseat it, reducing the pressure in $F$. This will cause the spool to rise restricting the orifice ($C$) between the inlet and outlet, until the pressure drops so that poppet 1 reseats itself. Therefore, the pressure at the outlet will be limited to the sum of the equivalent forces of the two springs. The control position of the valve is shown in Figure 6-25$b$. In normal operation ($C$) is never entirely closed. It must pass sufficient oil to permit the functions of the secondary pressure system and enough flow to hold the spool at the control position. This flow is continual and in valves used on molding machines is 60 to 90 in.$^3$/min.
Figure 6-35  Pressure reducing valve with constant pressure output (Vickers, Inc.).
Flow Control Valves

Flow control valves control the rate of flow of the oil in hydraulic circuits. They are used to control the velocity of cylinders, fluid motors, and valve shifting. They can be of fixed orifice or variable orifice. Once the size of an orifice has been set, the volume passing through it will vary with the pressure. A flow control valve of this type is called a nonpressure compensated valve. If the valve delivers a constant flow regardless of fluctuation of the inlet pressure, it is called a pressure compensated flow control valve. In circuits with fixed displacement pumps, the only way to vary the speed of component operation is with flow control valves.

The simplest flow control valve is a hole drilled in a plug in a pipe. These are usually small and used either to generate back pressure or to act as a snubber to prevent pressure surges to gauges.

There are two types of noncompensated, adjustable orifice, flow control valves—the needle valve and the globe valve. A needle valve has a long tapered point which seats against a corresponding cone. It is moved up and down by a threaded stem. It requires many turns to completely close. This allows for a fine control. They are primarily used as chokes in the pilot systems of valves and as a two way valve for gauges.

The globe valve has a sharply beveled disk which seats on a cone. It requires few turns to open fully and gives a coarse control. Its primary use in molding machines is as an “inching” valve (Figure 6-38). It is used to bypass the main pressure line to tank, mainly to permit slow motion of the cylinders during setup or repair.

When a fixed rate of flow is required regardless of pressure fluctuations (such as for an hydraulic motor in a screw machine), the valve must be pressure compensated. Figure 6-26 shows a schematic diagram of such a valve. The Y is an adjustable orifice which is set by the operator to determine the flow rate. The outlet is connected to the spring chamber area C. The inlet is connected to chambers A and B. The sum of the areas of the spool exposed to chambers A and B is equal to the area in spring chamber C. A pressure change in either the inlet or the outlet port will unbalance the forces on the spool causing the spool to move and change the clearance (X). This changes the pressure drop through (X) compensating for the pressure fluctuation. The spool always seeks a position to maintain a pressure drop which is equivalent to the spring force. Since the spring force is constant, the pressure drop will be constant. If the pressure drop between the inlet and outlet ports of a fixed orifice are constant, the flow rate will be constant. Therefore, in this valve the flow rate will be unaffected by pressure.
Servovalves

The type of fluid control devices we have discussed has no feedback as the result of their action. Their input is not controlled by the devices (cylinders, hydraulic motors) which they actuate. This is known as an open-loop system. One of the major faults of molding machine design is that we are measuring and controlling secondary actions. For example, we measure and control the pressure and flow of oil behind the injection plunger. We are really concerned with the velocity, acceleration and final position of the injection ram and with the pressure on the molded material. To accomplish this a closed-loop system or servocontrol is needed. In this way, the controller is continually aware of the momentary condition of the function to be controlled, compares this with the programmed function, signals to a servovalve or servopump which makes the adjustments
required to reduce the error to zero. This process is continuous.

The only servomechanism that has been used on molding machines for any length of time is one which is used to control the displacement of a variable volume pump. Servomechanisms and computer control are now becoming available in molding machines. There is every reason to believe that their cost will be reduced so that they come within the price range of the average molder.

There are two fundamental hydraulic systems for servocontrol. The servo-pump output is varied by feedback from a potentiometer (position control), tachometer (velocity control), or accelerometer (acceleration control). The system consists of a variable delivery pump, a control valve with a torque motor, an electronic amplifier, and the feedback. It is the pump output which is modulated.

In a servovalve system, only the used output portion of the pump changes the system's output. It has a servovalve, electronic amplifier, and a feedback unit (position, velocity, or acceleration). Both systems have a fluid motor or a cylinder to drive their load.

The electrical impulses which result from the comparison of the programmed and actual movements must be converted into hydraulic action (8). The two methods that can be used are a moving coil and a torque motor. The torque motor is used in servovalves found on molding machines. The motor armature is controlled by two coils. When the input signal is zero, the currents through the coils are equal and the armature is in a neutral position. When a signal is applied, the current is different in the coils, causing an armature movement proportional to the signal. This movement is transmitted by a thin stiff wire to the servovalve spool. This spool, which moves 0.006 to 0.010 in. in either direction, controls the control pressure oil which in turn controls the movement of the main spool, which controls the supply pressure. There are other methods of controlling the main spool such as flapper-nozzles and jet-nozzles. A fuller discussion of servovalves and circuits is beyond the scope of this book. Further information is available in Oil Hydraulic Power and Its Industrial Applications and Fluid Power Directory (see Bibliography, p. 549) and from manufacturer's literature.

PRESSURE INTENSIFIERS

Very high pressure pumps have a high initial cost and maintenance. When relatively small amounts of oil are needed, such as maintaining 5000 psi in a clamp holding circuit, the initial cost and maintenance suggest the use of a pressure intensifier (booster). Pressure is generated by means of using the difference in areas of two pistons, such as in an hydraulic jack. The increase in pressure will depend on the ratio of the piston areas. The flow will vary inversely as their ratio.