For example, if the ratio of the large to the small piston area is 7 : 1, and the oil pressure behind the large cylinder is 500 psi, then the small cylinder will produce oil at 3500 psi. If the flow rate to the large end of the cylinder is 35 gal/min, the flow from the small end would be 5 gal/min. The pressure intensifier, therefore, can also be used as a volume amplifier by applying the pressure on the small end and is used as a prefill system on some molding machines instead of a prefill check valve.

Figure 6-27 shows a single stage pressure intensifier. When \( A \) of the four way valve is energized pressure is blocked to the back of the intensifier, port \( E \), by the check valve and the sequence valve. Oil goes into port \( C \) through the front end of the intensifier, out port \( D \) into the back of the work cylinder. When the work cylinder meets resistance and pressure builds up, the sequence valve opens permitting oil to go into the back of the intensifier, port \( E \). As the intensifier plunger moves forward it seals off port \( C \) and applies the intensified pressure through port \( D \) into the work cylinder.

When the cycle is complete, \( B \) is energized shifting the four way valve. Oil under pressure enters the rod end of the work cylinder and the front of the intensifier through port \( F \); \( C \) and the sequence valve are ported to tank. This closes the sequence valve. Oil from behind the intensifier flows out through port \( E \) and the check valve. The oil behind the work cylinder rapidly forces the intensifier plunger back and goes to tank through port \( C \).

Obviously the system will work as long as there is enough oil in the chamber in front of the intensifier to overcome leakage. Otherwise a double stage pressure

![Figure 6-27 Single stage pressure intensifier.](image)
intensifier can be used (Figure 6-28). It consists of a reciprocating double-ended piston. When the piston completes its stroke in one direction it mechanically shifts over a three way valve, which is shifted in the opposite position hydraulically. Let us consider the action in the diagram with the intensifier moving toward the right. Low pressure is applied behind the intensifier through port $F$ and through the check valve $(5)$ to port $E$. The previous cycle has pushed plunger $A$ so that pressure has piloted $A\cdot1$ and $A\cdot2$. The pilot pressure at $A\cdot2$ has extended the plunger $B$, and has exhausted $B\cdot1$ and $B\cdot2$ to tank, so that these valves could shift. As the plunger moves, oil in front of the large piston area is exhausted through port $H$ to tank. Intensified, high pressure oil leaves at port $G$ and flows through check valve $7$ to the main circuit, through $J$. It is blocked by check valve $8$. Because the pressure at $J$ is much higher than at port $E$ check valve $6$ will remain closed. When the piston hits plunger $B$ the valve shifts. Low pressure oil now activates $B\cdot2$ which resets plunger $A$, and connects $A\cdot1$ and $A\cdot2$ to tank. It also shifts $B\cdot1$ which moves the four way directional control valve and reverses the procedure. High pressure oil will now come from port $E$ past check valve $6$ to $J$. The booster operates automatically and does not raise the horsepower requirement. For example, using a $5\cdot1$ booster ratio, 20 gal/min entering at 500 psi will leave at approximately 4 gal/min and 2500 psi.

![Figure 6-28 Double stage pressure intensifier.](image-url)
Aside from their use in the molding press, they are valued also in tools for punching, pressing, riveting, shearing, and such. Pressure intensifiers can be powered with compressed air instead of hydraulic oil and, as such, are commonly used for other tools, but not on molding machines.

**ACCUMULATORS**

An hydraulic accumulator is a devise which allows the oil to store energy for later release (9,10,10a). The energy can be stored by raising weights (gravitational), compressing springs (mechanical), or compressing gases (pneumatic). They are analogous to batteries in electrical circuits, and springs in mechanical circuits.

**Gravity Type**

The simplest accumulator is a gravity type which consists of a cylinder in a vertical position on whose piston heavy weights are placed. Oil is pumped into the bottom of the cylinder raising the weight. When the oil is released, gravity will force the oil out at a constant speed and constant pressure. This is the only hydraulic accumulator which will do so. The disadvantages of this type (large bulk and large weight) has precluded its use for molding machines.

**Spring Loaded Types**

Spring loaded accumulators work by having the oil pressure compress springs. It consists essentially of a cylinder with a sliding piston with suitable packing. Springs are placed on one side of the piston and the oil pumped on the other side. They are occasionally used in molding machine circuits; for example, when it is necessary to maintain pressure during the shifting of a valve.

**Gas Loaded Types**

Gas loaded accumulators are used on injection molding machines. Hydraulic fluid will compress less than 2% at 5000 psi. This means that when 2% of the compressed fluid has been released, the pressure in the system is 0. On the other hand, gases are very compressible and easily store energy. They follow Boyle's law; which says that the product of the pressure and volume of the same amount of gas is constant at a given temperature. In other words, if the volume is decreased by a factor of 10, the pressure increases by the same factor 10; that is, 10 gal at 200 psi has the energy equivalent of 1 gal at 2000 psi. The gas accumulator is a device which allows the hydraulic fluid to compress the gas in charging, and allows the expansion of gas in discharging, to provide energy to the fluid.
Nonseparator Accumulators

A nonseparator type accumulator consists of a shell with the gas pressure on top and the oil on the bottom. The gas acts directly on the oil without a separator between them. Its main advantage is its ability to accommodate large volumes of oil. Because of the possibility of dissolving gas in the oil and its sluggish operation it is not used on molding machines.

Separator Accumulators

The separator type keeps the oil and gas separate. It is accomplished either by a piston, diaphragm, or bladder. The piston type consists of a cylinder with a piston containing the appropriate seals, which separates the oil from the gas. They are relatively costly to build and to maintain. The diaphragm type consists of two hemispheres with a synthetic rubber diaphragm between them. Because of its small weight to volume ratio it is mainly used in airborne applications.

Bladder Accumulators

The bladder type consists of a shell with a synthetic rubber bladder into which is charged the gas under pressure. The other end receives the oil. Its main advantage is a positive seal between the gas and oil with a light weight separation. This provides for quick pressure response for pressure regulating, and shock absorbing uses. Air is never used to charge oil accumulators as a failure could result in an explosive mixture. Nitrogen is the gas of choice.

Uses of Accumulators

Accumulators are used to dispense lubricants to various parts of the machine. The lubricant is pumped into the bottom part and is dispensed by either supplying pressure to the top part or having continual pressure metering out the lubricants. Another application is as a shock absorber. Hydraulic shock (water hammer) can be effectively dampened by using an accumulator near the source, usually a directional control valve. Persistent leakage problems are often solved this way.

A major use of accumulators in injection molding is to provide an additional source of volume and pressure when needed. Hydraulic cylinders are commonly used to move cams on a mold. To achieve rapid motion large pumps would be required. Putting a properly sized accumulator, connected to the pump output, will give the volume of oil required for rapid motion. The accumulator is recharged between cycles.

There is considerable time during the molding cycle when the high volume, low pressure pump is not used. By using an accumulator, the speed of the
Figure 6-29 Use of accumulator to increase speed of existing circuit.
cylinder will be appreciably increased without changing the pumps (Figure 6-29). Each pump has its own pressure control. Assuming the accumulator to be fully loaded, solenoid $F$ is energized. The low volume, high pressure pump supplies oil through check valve 5, the high volume, low pressure pump through the accumulator control valve and check valve 7, and the accumulator through check valve 6. In other words, the oil in the accumulator is being rapidly added to the combined output of the two pumps. When resistance is met, the pressure switch is activated, shifting the accumulator control valve. The low volume, high pressure pump builds up and maintains the clamping force in the cylinder. The high volume, low pressure pump charges the accumulator through check valve 8. Since the pressure of pump 1 is higher than that of pump 2, check valve 6 remains closed. The accumulator recharges. When solenoid $R$ is energized, the cylinder returns again using the accumulator's oil. The accumulator is then recharged for the next cycle.

A common use of accumulators is for intermittent operations, where its use will reduce the size of the hydraulic power unit. An excellent example is the use of a cylinder for pulling cores or cams, (Figure 6-30). The accumulator slowly stores the hydraulic fluid from the clamp-end pumps, and releases it rapidly upon demand, for the auxiliary operation. The example on p. 534, needing 18.4 g/min, would require a 12½-hp power unit. With an accumulator, a 5-hp unit is more than sufficient. It is used to provide power for manual operation, if the main system is bypassed, or not operating (i.e., during the mold set-up). It is controlled by a pressure switch which starts the motor only when there is not enough pressure in the accumulator. Check valve 1 prevents oil from reaching the clamp circuit, which might be dangerous. Check valve 2 prevents the clamp oil from flowing into tank through the auxiliary pump.

**FLUIDICS**

Fluidics is the technology of liquid or gas streams and their reactions to control jets (11). As such, they contain no moving mechanical parts. Their use is in logic or decision-making functions and potentially can be used in place of relays and solid state controls.

Because they have no moving parts and replace electronic and electromechanical devices they have a number of distinct advantages.

1. For practical purposes they should never wear out.
2. They are insensitive to vibration and shock.
3. They generate insignificant amounts of heat.
4. The temperature and nature of the fluid is limited only by the material of the device.
Figure 6-30 Use of accumulator to operate auxiliary cylinder.
5. They can be made of almost any material.
6. They can be mass produced (injection, compression molding) and inexpensive.
7. They can be made extremely small.
8. Because there is no electricity, shorts, shocks, and wire are eliminated; also, coils and contacts do not have to be replaced.
9. Because fluidics run at low pressures the connecting elements can be plastic tubing instead of the metallic connectors with their problem of leakage.
10. Plastic tubing is easy to install, change, and replace.
11. The power consumption is low ranging up to several watts.

Fluidics have certain disadvantages:

1. They are slow (milliseconds) compared to electronic controls. This is acceptable for molding machines.
2. They require a continual supply of fluid whether they are on or off.
3. Their low power output, at this time, is not enough to drive a cylinder or hydraulic motor directly.
4. They must "interface" with an amplifier to enlarge the signal and operate the power devices. They of course, have moving parts.

Fluidics is so new that one cannot predict whether these limitations will be overcome.

In addition to control circuits, fluidics can be used in accurate low pressure closing; they also check if all mold components and inserts are in place; and can be used to control the flow of plastic in a mold to encapsulate a part without supporting it mechanically.

Principles of Fluidics

Fluidic devices, which can be analog or digital are based on three principles. Analog devices have an output signal proportional to the control signal. Digital devices are switches which are either on or off. Most fluidic devices are of this type. As the theory and technique improves more analog devices will be made.

The first principle used in the "Coanda effect" which states that a fluid stream will continue along its existing path along a wall surface until deflected by a jet. It will then remain on the next surface until moved again by an external force. Figure 6-31a shows a flip-flop fluidic device. The main pressure enters from port P. If the control jet C-I is activated, the pressure will flow through port 0-I. If control pressure is now applied from port 0-2, the main stream will switch and exit through port 0-2. By adding a bias port and/or combining units such logic devices, among others, can be made: OR, AND, NOT, NOR, NAND. Other controls of this kind include binary flip-flop, half adder and summing
Figure 6-31 Fluidic devices: (a) flip-flop switch, (b) turbulence amplifier, and (c) vortex amplifier.
amplifiers. If the control flow of ports C-1 and C-2 were divided by another control device the outputs would be at 0-1 and 0-2, and would be proportional to the respective inputs. This is a proportional amplifier.

The second principle involves the transition from laminar to turbulent flow by a jet (Figure 6-30b). The turbulence amplifier has the pressure entering at port P, maintaining its laminar flow so that the same pressure will be delivered at port 0. If a jet with enough energy is introduced at C-1 or C-2 it will break up the laminar flow, cause turbulence so that negligible pressure is built up at the output.

The third type of fluidic device is called a vortex amplifier and works on the principle of conservation of momentum (Figure 6-30c). In its normal state the pressure will flow directly through the valve and out the outlet port 0. When a controlled jet impinges itself tangentially on the main pressure jet flow, it causes it to rotate, creating a vortex, with a high pressure drop from the circumference to the outlet. This back pressure stops the flow of the power jet. The output will vary, depending on the strength of the control jet, making the vortex amplifier one of the better analog fluidic devices. While this valve operates at low fluidic pressures, it can also operate at the hydraulic pressures of a molding machine.

Fluidics is just developing and will probably have considerable applications in the molding machine and plants. It is safe to assume that as these developments occur they will be reported in the literature (12).

**PUMPS**

A pump is a mechanism through which an external source of power is used to apply force to a liquid. Molding machines use electric motors as the power source. A pump does not pump "pressure." It creates flow. Pressure is resistance to flow. The pump cannot produce pressure in itself since it cannot provide resistance to its own flow. A pump is not a compressor as such, because at low pressures oil is virtually incompressible.

Pumps can be classified according to the manner by which they discharge their liquids (such as rotary pumps, centrifugal pumps, and gear pumps). They are also classified as positive or nonpositive displacement pumps. A positive displacement pump (piston pump) is one where at a constant shaft speed a specific volume of liquid is delivered regardless of the resistance of the circuit. A nonpositive displacement pump (centrifugal pump) is one in which the volume delivered per shaft rotation is dependent upon the resistance of the circuit to flow. A positive displacement pump gives constant delivery. If the mechanism can be arranged to alter the volume delivered, it is called a variable displacement pump. Nonpositive displacement pumps are not found in the hydraulic systems of molding machines. They are used in the water system, particularly on water
cooling towers. The following discussion relates to positive displacement pumps.

There are a number of specifications that apply to pumps. The *volume* of fluid pumped per revolution of the shaft is a function of the geometry of the pump. It is given either in cubic inches per shaft revolution or gallons per minute at a given shaft speed. In variable displacement pumps the maximum and minimum are given.

The *volumetric efficiency* is the ratio of the theoretical volumetric output at zero pressure over the actual output at a given pressure. It is a measure of the fluid leakage inside the pump and depends on the operating speed, pressure, and construction.

The *mechanical efficiency* is the ratio of the output horse power over the theoretical (geometric) input horse power at a specific volume output and pressure. It is a measure of the frictional loss. The *overall efficiency* is the product of the volumetric and mechanical efficiencies.

The *pressure range* is the maximum and minimum pressures at which the pump is designed to operate.

The *speed range*, given in revolutions per minute, is the maximum and minimum limits for the efficient operation of the pump. Usually pumps run at a synchronous motor speed.

The *fluid* specification gives the recommended oil, its viscosity, its viscosity index, filtration methods, and cleanliness level.

The *temperature range* is the maximum and minimum safe operating temperatures that will give an efficient pump operation with the recommended oil and not adversely effect the seals and packing.

The three types of positive displacement pumps found on injection machines are gear pumps, vane pumps, and piston pumps.

**Gear Pumps**

An external gear pump consists of two gears which mesh together in a closed container. One gear is attached to the motor and the other rotates freely on a shaft. As the gears rotate, the volume between the gear teeth will increase on the inlet side lowering the pressure and drawing up oil from the reservoir. Conversely, on the outlet side the volume will be reduced causing the oil to flow. The gears are usually of the spur type. Helical gears are used which are quieter but develop an end thrust. This is eliminated by using closed center herringbone gears.

They have high volumetric efficiencies up to 93% and general overall efficiencies of 75%. The pressure range is 250 to 3000 psi, and a volume of 0.2 to 150 gal/min. They are inexpensive, have few moving parts, and are relatively insensitive to dirty fluid. They are used on pilot pressure systems and as priming pumps for large volume, high pressure pumps.
External gear pumps have the teeth projecting outward from the center of the gears. In internal gear pumps, one gear has its teeth projecting outward and the other, on the periphery of the casing, has its teeth projecting inward towards the center of the pump. The inner gear always has fewer teeth than the outer gear. They are not ordinarily used on molding machines.

Vane Pumps

The vane pump is widely used on injection machines. The pump (Figure 6-32) consists of a drive shaft on which is attached a rotor that is not concentric with the ring. The rotor has slots in which the vanes slide. Centrifugal force or springs keep the vanes touching the ring. As the pump rotates, the volume of a segment bounded by the two vanes, ring, and rotor increases on the suction side, creating a vacuum. Air pressure on the oil in the tank or oil from a priming pump fills this volume through the inlet port while on the suction side. The inlet and outlet ports continue for almost the full length on each side. On the pressure side of the pump, the volume of the segment between vanes decreases, forcing the oil out of the outlet port, creating flow.

![Diagram of Vane Pump](image_url)

**Figure 6-32** Vane pump with unbalanced shaft.
The vane pump illustrated is unbalanced, in that there is pressure on the right-hand side and suction on the left-hand. This would tend to push the whole shaft toward the left and give relatively rapid wear. Vane pumps designed to prevent this are called balanced pumps which are used on molding machines. It is accomplished by shaping the cam ring with two lobes. Variable displacement vane pumps shift the cam ring. Therefore, they are inherently unbalanced because they use a single lobe cam.

Vane pumps are rugged and not too susceptible to dirty oil. Their efficiency is high, volumetric ranging from 85 to 90% and overall 82 to 87%. Additionally they keep their high efficiency for a long period because the wear of the vane ends upon the ring is automatically compensated. They are easy to repair with standard kits to replace the moving parts. The pressure range is from 250 to 3000 psi and delivery from 0.5 to 250 gal/min. The delivery can be altered by changing the cam ring.

Vane pumps, like other types, also come with two units on one shaft to be run by one motor. They may be of any size or combination and are hydraulically independent. For the high pressure ranges one is used to supercharge the other.

**Rotary Piston Pumps**

Rotary piston pumps are either axial, where the pistons are parallel to the axis of the shaft, or radial, where the pistons are perpendicular to the shaft. The three types of internal valving are flat or plate type (Figure 6-33), check valves, or pintles (Figure 6-34).

A piston pump uses a piston in a hole to decrease or increase the volume of a chamber (Figure 6-33). The action is analogous to a vane pump. The shaft turns the cylinder block. The pistons are anchored to the rotating cam ring which is set at an angle. As it rotates toward the top position in the illustration, the piston pulls back increasing its volume and creating a vacuum which is filled with oil through the inlet port. As it rotates downward, the piston is forced in, expelling the oil through the pressure port, until it reaches the bottom position, where the cylinder has its minimum volume. The port plate is shown on the left.

If the cam plate and port plate are nonadjustable the output per shaft revolution will be constant. This is called a positive displacement, fixed volume pump. Supposing the cam plate angle was changed so that the cam ring was perpendicular to the shaft. There would then be no motion of the pistons relative to the block. The pump would not deliver any oil. By tilting the cam ring slightly, a small displacement would occur and the volume would be small. As we vary the cam plate angle, we vary the displacement of the pump. The pump would now be called a positive displacement, variable volume pump.

There is another way of accomplishing the same result. If the cam plates were
Figure 6-33  Positive displacement axial piston pump.

Figure 6-34  Variable displacement radial piston pump. (The Oilgear Company).
at the angle to produce maximum displacement, and the port plates rotated 90°, the pump would deliver no oil, because an equal volume of inlet and outlet ports are connected to each other. By altering the amount of rotation of the port plate, the volume per shaft rotation can be infinitely varied. This, too, would be called positive displacement, variable output pump.

Figure 6-34 shows a variable displacement radial piston pump. It consists of a stationary pintle upon which is mounted the rotating cylinder containing the pistons. The pintle has four holes drilled parallel to the shaft axis. It is milled under the piston holes so that two act as inlets and two as outlets. The cylinder assembly is driven by the shaft. Centrifugal force and oil pressure keep the beveled heads of the pistons against the thrust ring of the rotor. This causes the rotor to rotate with the cylinder. The rotor is attached to the slide block. The illustration is a top view of the pump looking down, an horizontal view. The slide block slides back and forth. In the illustration it is fully moved to the hand wheel or control side. The pistons have their maximum movement on the hand wheel side, and decrease in volume as they rotate 180°, sending oil through the outlet ports of the pintle. If the slide block is central, the pistons will have no radial movement, and no oil will be delivered. If the slide block moves toward the bottom of the illustration the ports will reverse, the pressure ports becoming tank ports and the tank ports becoming pressure ports. This type pump has been used very successfully on injection molding machines, eliminating the four way directional control valve for the injection and clamp cylinder (13). The shock transmitted is so small that the author has seen a nickel balanced on its end on the stationery platen remain so during dry cycling of the machine. The main pump is supercharged with a gear pump. Both pumps have their own built-in relief valves.

The location of the slide block is controlled by a hand wheel. In any given position the pump acts like a positive displacement unit. The control need not be a hand wheel. It can be an electrically controlled motor. This controls the movement of the slide block very accurately, so that the volume of fluid can be varied smoothly over a stepless range from zero to maximum output in either direction. This characteristic is also true of the other methods of control. A pressure unloading control will hold a preset pressure and shift the slide block so that only enough oil is delivered to maintain this pressure. This eliminates excess heating, power loss, relief valves, unloading valves, and bypass valve. Hydraulic or electric controls are available to change the volume of the pump at any given time to a specific preset delivery. This type of pump is ideally suited for electrohydraulic servo control.

Some of the advantages of variable displacement pumps are infinitely variable pressure and volume without external valving and piping; lower power consumption; lower heat development; more flexibility in molding; use of servocontrol; and longer life.
Some of the disadvantages are higher initial cost; more expensive repair; longer downtime, because repairs cannot usually be done in the plant; and larger weight and size.

Piston pumps are the most efficient, with volumetric efficiencies from 90 to 98% and overall efficiencies about 90%. Pressure ratings are from 600 to 5000 psi and volume from 0.5 to 2200 g/min.

**Horsepower Requirements for Pumps**

The input horsepower required for an hydraulic systems is

\[ HP = 5.82 \times 10^{-4} \, P \, Q \]  \hspace{1cm} (6-10)

where

- \( HP \) = input horsepower
- \( P \) = pressure (psi)
- \( Q \) = flow rate (g/min).

Let us determine the horsepower requirements for the hydraulic system described on p. 488. Assume that a 7000-lb force is required to seal the cam. The 3-in. diameter cylinder has a piston area of 7.07 in\(^2\), the volume required is 18.4 gal/min. Substituting (1-18)

\[ P = \frac{F}{A} = \frac{7000}{7.07} = 1000 \text{ psi} \]

Using this in (6-10)

\[ HP = (5.82 \times 10^{-4})(1000)(18.4) = 10.7 \text{ hp} \]

Assuming an 85% overall efficiency

\[ HP = \frac{10.7}{0.85} = 12\frac{1}{2} \text{ hp} \]

This is a very large power supply and can be substantially reduced by using a small accumulator, (Figure 6-30).

**Pump Maintenance and Trouble Shooting**

The maintenance of pumps essentially is one of keeping the oil clean. Normal wear is taken care of by replacing the bearings and moving parts. The following suggestions do not cover the control mechanisms of variable displacement pumps.
**Pump Not Delivering Oil.** This can be readily checked by opening a connection on the pressure side of the pump. The problem could be one or more of the following:

1. Not enough oil in the tank.
2. Oil intake line, filters, or strainers are clogged.
3. Air entering in the suction line. This can be indicated by unusual loud noises.
4. Pump shaft turning in the wrong direction. Maintenance might have inadvertently reversed the three phase motor input during repair.
5. Pump shaft speed too low. This can be caused by single phasing of a three motor or a loose or slipping coupling.
6. Mechanical trouble. Usually this is accompanied by noise in the pump. The usual mechanical troubles are worn bearings, broken shafts, rotors, pistons, or vanes.

**Pump Not Delivering Full Pressure and Volume.** This can be checked by collecting the unrestricted flow of the pump during a timed interval. A restricting valve and pressure gauge is put over the pump output and the output similarly measured at a specific pressure. These figures are compared to the rating of the pump. If they are acceptable then the problem is downstream in the system.

1. The internal relief valve setting of the pump (if there is one) is too low or acting incorrectly.
2. The wrong viscosity oil has been used permitting too much internal leakage, or the oil is too hot, lowering its viscosity.
3. Broken, worn or stuck pump parts. This requires disassembly of the pump.

**Noisy Pump.** This condition might be due to one of the several causes listed below:

1. Air leaking into the system.
2. Cavitation, which is oil starvation of the pump. The intake filter system should be checked.
3. Air leaks due to a worn shaft packing.
4. The pump might be out of line with the motor.
5. The coupling can cause noise from wear or might require lubrication.
6. The noise might come from chattering relief valves in the pump.
7. Internal causes within the pump.

**Overheating.** Common reasons for overheating follow:

1. The heat exchanger might be dirty, has insufficient water or the inlet water has too high a temperature.
2. Oil viscosity is too high.
3. The discharge pressure is too high for the design of the system.
4. Internal leakage in the pump is too high. This is caused by wear.
5. Leakage in the system. If a valve is not functioning properly, or a piston ring is worn, the pump will operate above the system design conditions to make up for the leakage. Additionally, oil flowing with high velocity through the leakage points which act like small orifices will overheat.
6. The oil in the reservoir is low. The reservoir acts as an heat exchanger and insufficient residence time in the reservoir will reduce the heat dissipation of the system.

HYDRAULIC MOTORS

Hydraulic motors are the reverse of hydraulic pumps. In a pump, power is applied to the shaft which turns the pump causing oil to flow. In an hydraulic motor, oil is forced through the motor which causes the shaft to turn. A pump is designed to deliver the maximum volume per shaft rotation. Therefore, the design emphasis is on volumetric efficiency. The hydraulic motor converts energy in a fluid to rotary motion and torque. The emphasis is on mechanical efficiency. For this reason there is a slight difference in design between a motor and pump, though they operate using the same principles. The three types of hydraulic motors are gear-type, vane-type, and piston-type. They can have fixed or variable displacements.

Displacement

The displacement is given as the amount of fluid required for one shaft revolution. Units are usually cubic inches per revolution. A fixed displacement motor provides constant torque and variable speed (at a given pressure). The speed is controlled by changing the flow rate to the motor. A variable displacement motor provides variable torque and speed. With constant pressure and input flow, the ratio between torque and speed can be varied to meet the load requirements by changing the displacements. Varying combinations of torque, speed and power can be had by combining pumps and motors with fixed or variable displacements.

Speed

The speed of an hydraulic motor is a function of the flow rate and displacement, less the internal leakage. Volumetric efficiency is a ratio between the theoretical speed of the motor for a given flow and the actual speed developed.
Torque Output

Torque output, which is expressed in inch-pounds or foot-pounds, is a function of the motor displacement and the pressure. Torque is usually reported for a specific pressure drop across the motor. Mechanical efficiency is the ratio of actual torque delivered to the theoretical torque. In a fixed displacement motor, torque varies directly with the pressure.

The relationship between horsepower, torque, speed, and displacement is given in (1-11) (1-12), (6-10), (6-11), and (6-12):

\[
(6-11)
\]

where \( T \) = torque (ft-lb)  
\( D \) = displacement (in\(^3\)/rev.)  
\( \Delta P \) = pressure drop across motor (psi).

\[
HP = \frac{FL}{6600T} \tag{6-12}
\]

where \( HP \) = horsepower  
\( F \) = force (lb)  
\( L \) = length moved (in.)  
\( T \) = time (sec)

Motor in Use

Hydraulic motors are primarily used to turn screws in the plasticizing chamber. With the proper combination of hydraulic pump and motor, stepless variations in speed and torque are available. This is of great value in molding. In the event they are overloaded, they will stall without mechanical damage. For these reasons, too, they are well adapted for auxiliary operations, such as turning cores in an automatically unscrewing mold.

Figure 6-35 shows an hydraulic motor circuit with slow deceleration and braking controls. It consists of a motor, pump, pressure compensated flow control valve, pressure relief valve, four way, three position, directional control valve. The pressure compensated flow control valve regulates the speed of the motor by metering part of the pump flow to tank. This is known as a meter to waste installation. The flow control valve could have been put in series with the inlet or outlet of the hydraulic motor. The illustrated method is more efficient because the pump output pressure will only be enough to overcome the work resistance.

When solenoid \( R \) is energized the motor is in its normal operating position. Oil from the pump goes through the motor whose output goes directly to tank.
Figure 6-35  Hydraulic motor circuit with slow deceleration and braking.
The maximum torque is controlled by the pressure relief valve. The speed is controlled by the pressure compensated flow control valve. To slow down normally, the four way valve is shifted to its neutral position. The pump and motor are ported to tank and the motor coasts slowly to a stop. If it is desirable to stop the motor quickly, solenoid B is energized, the pump is dumped to tank, and the motor exhaust goes to the pressure relief valve where it is blocked, quickly braking the hydraulic motor.

Plasticizing the more viscous materials requires high torque at low speeds. This can be accomplished by attaching two hydraulic motors of equal displacement to the gear reducing transmission (Figure 6-36). When the three position, four way valve is in the position shown on the drawing oil goes to both hydraulic motors. Since the oil flow is divided between them they will go at a slow speed. The torque, however, is constant and depends on the pressure control setting. Therefore, the torque will be additive and the circuit will have low speed and high torque. If the valve is shifted into detent position 3, oil will only flow through motor 3. The return oil exhausts through check valve 2. Check valve 1 permits oil to be on both sides of motor 1 so that it does not act as a brake. The screw will now have one-half the torque but double the speed as compared to both motors operating. This is the high speed-low torque range. With the directional control in detent position 1 motor 1 will run instead of motor 3. The motors need not be of equal displacement allowing three speed-torque ranges.

**HYDRAULIC CIRCUITS**

Hydraulic circuits used in injection molding machines are relatively simple to follow, when broken into their component parts (Figure 6-37). There is a pump circuit with its related oil cooling and filtering. Cylinder plungers have safety controls, directional controls, speed controls, pressure controls, regenerative controls, and prefill controls. Hydraulic motors have pressure and speed controls. Examples of these circuits can be found throughout this chapter. Figure 6-38 shows an oil filtration circuit with its independent pump and motor. This can come with the machine or be added afterwards. It has its own electric motor and pump F. Oil is drawn from the tank through check valve F which prevents drainage of the system when the pump is off. It goes through the filter and back to tank. As the filter clogs up, more pressure will be required to force the oil through. In most filter systems, the cartridges should be replaced at about 60 psi. The unloading valve G is set at 60 psi. This prevents a pressure build-up beyond the capacity of the filtering element. Should the element be destroyed, it would go into the oil tank. A magnet is put into the oil tank to attract small iron particles from erosion or breakage in the system, or any larger particles which might get in accidentally.
Figure 6-36 Two speed-torque ranges using two identical hydraulic motors.

**High-Low Pump Control Circuit**

Variable volume pumps will deliver just enough oil to maintain the pressure required by the load. Fixed displacement pumps use their full volume for moving a cylinder and then have to dump most of the pumped volume over a relief valve while the system is being held under pressure. This is wasteful of power and generates heat which is expensive to remove. To overcome this, two
pumps are used. They are used together to provide the volume for the rapid motion. The smaller of the two is then used to maintain the pressure while the larger is unloaded to the tank at low power consumption. The other section of Figure 6-38 shows this. Low volume-high pressure pump 1 and high volume-low
pressure pump 2 are turned on a common shaft by the electric motor. Oil is supplied from the tank through a strainer. If the strainer is clogged, it will be bypassed by check valve 3, which will open at 60 psi. This prevents cavitation or oil starvation of the pump. When a directional control valve shifts to move a cylinder, the output of both pumps will flow into the system. When the cylinder meets resistance, the pressure will rise. When it reaches the 400 psi setting of the unloading valve 4, high volume low pressure pump 2 will unload to tank. The pressure will continue to rise with oil supplied from low volume-high pressure
pump 1 until it reaches the setting of the relief valve 6. This relief valve 6 will bypass that flow of pump 1 not required to maintain the leakage through the valve cylinders and other parts of the hydraulic system. Oil from pump 1 is blocked from pump 2 by check valve 2 because pump 2 is at a higher pressure than pump 2.

There are times during the molding cycle when the output of the low pressure pump is required above the 400 psi unloading pressure. This might happen during injection forward. If solenoid B is energized, pilot oil will enter the control chamber of the unloading valve 4, preventing it from unloading regardless of the pressure of the system. Solenoid B it usually controlled by a timer, or it can be positionally controlled with a limit switch mostly commonly activated by the injection plunger motion.

Valve 5 is a hand-operated globe valve which bypasses the output of both pumps to tank. The inching valve is used to move the cylinders slowly during setup and maintenance.

Let us see how this circuit is used in a molding machine. Most fixed displacement power supplies have an additional low pressure high volume pump which is used as a holding pump for the clamp circuit. After the gate is closed all three pumps deliver oil to the clamp circuit. As the pressure begins to rise in the clamp circuit, the third low volume, high pressure pump is separated from the other two pumps (1 and 2) which are illustrated in Figure 6-38. (One way of separating them is show in Figure 6-12). The circuit (Figure 6-38) is timed so that at this moment, the injection forward control valve will be shifted to permit oil to go behind the injection ram. This will drop the pressure in the lines connected to pumps 1 and 2 and will close the unloading valve 4. They will both send their oil there until the pressure builds up to 400 psi when pump 2 will unload through unloading valve 4. It can be prevented from unloading by energizing solenoid B. The injection pressure will be controlled by pressure relief valve 6. More often there will be two pressure controls with a circuit similar to Figure 6-22.

When the injection four way valve shifts, as it would in a plunger system, the pressure will drop in the lines from pumps 1 and 2 and both pumps will deliver oil to return the plunger. The unloading operation will be repeated. On clamp return, the shift of the four way valve will open the pump separation two way valve (Figure 6-12), dropping the pressure and bringing the three pumps into the circuit to open the machine.

CLAMP CONTROL

A typical clamp control circuit for a toggle machine is shown in Figure 6-39. System pressure flows through the flow control valve 1 and check valve 2, into
Figure 6-39  Clamp control hydraulic circuit.

the hydraulically operated, spring centered directional four way clamping valve. Pilot pressure is supplied through a flow control valve 3, to the solenoid operated pilot valves. When the pilot forward solenoid PF is operated, the valve shifts and pilot pressure oil goes into the safety valve. This is mechanically
operated and only closes when the gate is closed. Only when the gate is closed does pilot pressure oil flow into the clamp forward side \((HF)\) of the four way valve. It shifts so that pressure is sent to the back of the clamp cylinder.

Regardless of the position of deceleration valve \(D\), oil will flow without restriction through check valve 4 during clamp forward. The clamp return movement of the platen can be slowed down by energizing solenoid \(D\). This closes the oil path through that valve. Since it cannot flow back through the check valve 4 it must flow through the restricted opening of the deceleration flow control valve 5, and move at a speed determined by that valve setting.

The clamping system’s main pressure control valve 6 has a secondary pressure control 7, which is connected through the solenoid operated low pressure relief valve 8. When the mold closes and there is no obstruction, a limit switch is closed which energizes solenoid \(LP\), and blocks out the low pressure relief valve 7. Full system pressure is now obtained in the clamping system. If there is any obstruction on the mold, the limit switch will not be contacted. Solenoid \(LP\) will not be energized, and the clamping pressure will never be higher than the setting of the low pressure relief valve 7. This is set low enough to prevent damage to the mold. Electrically, the circuit will prevent the injection ram from coming forward and may also set off an alarm. This is called the low pressure, mold safety circuit.

INJECTION CONTROL CIRCUITS

The injection control system (Figure 6-40) is fed by the system oil pressure through the solenoid operated, hydraulically piloted, spring returned, four way valve. When the pilot solenoid for injection forward \((PF)\) is energized, the pilot valve shifts, sending oil into the injection forward side \((F)\) of the main valve. This shifts the spool sending oil into the back of the injection ram. The regenerative circuit blocks the return flow at check valve 1, and sends it through check valve 2, back into the pressure line, combining it with the pump flow. Normally it would go to tank and have to be repumped. This continues as long as the sequence valve 3 remains closed. When the injection pressure rises to the sequence valve setting, 400 psi, it opens, permitting the small amount of oil in front of the injection ram to go to tank. On injection return, (solenoid \(PR\) energized sending oil to \(R\) side of main valve) the oil returning the injection ram goes through check valve 1. The purpose of the regenerative circuit is to increase the injection forward speed at low pressure.

When the pilot valve shifts for injection forward, the pilot oil branches off to be used as the booster oil supply. In this circuit, then, the unloading valve for Figure 6-38, can be blocked only during injection forward.

The pressure reducing valve 6, in Figure 6-40 will supply oil to secondary
Figure 6-40 Injection control hydraulic circuit.
hydraulic mechanisms such as hydraulic knockouts and cams. The carriage on which the injection cylinder is mounted is controlled by a manually operated, three position, four way valve. The speed is controlled by a needle valve 8. The pressure reducing valve 7, is adjusted to limit the seating pressure of the nozzle against the sprue. Too much pressure might push the mold from the platen.

RECIROCATING SCREW CIRCUIT

The hydraulic system for a circuit to operate a reciprocating screw. (Figure 6-41) is fed through a solenoid piloted, hydraulically operated, four way valve. When the hydraulic motor solenoid M is energized, the oil goes into the “screw on” solenoid S. In its normal position the pressure outlet port is blocked. When S is energized it sends oil through the hydraulic motor, which turns the screw. The torque of the motor is controlled by the pressure relief valve T. A bleed-off circuit controls the speed of the hydraulic motor, using a pressure compensated flow control valve 1. It can be blocked by a manual shut off valve 2 to give maximum motor speed. The two check valves 3 and 4 keep the ram end of the injection cylinder full of oil at all times.

As the screw turns the plastic is melted and collects in front of the screw. This forces back both the injection screw, transmission, and the injection cylinder ram. As the injection cylinder ram moves back, the oil return is blocked by check valve 5. It is also blocked by the gauge valve, whose back pressure solenoid BP was energized in parallel with solenoid S. The pressure gauge reads the back pressure of the oil. In molding, the back pressure rarely exceeds 300 psi, while the injection pressure might be over 2000 psi. To set the back pressure more accurately, a low range pressure gauge is used. The back pressure sequence valve 6 remains closed until the preset pressure is reached. Then the valve opens and excess oil dumps to tank. This controls the pressure on the material while it is being plasticized. When the carriage has been pushed back by the plastic to a preset location, a limit switch is contacted deenergizing the “screw-on” solenoid S and stopping the hydraulic motor, and deenergizing solenoid BP.

The plastic material could be under enough pressure to drool out of the nozzle. To prevent this the “suckback” solenoid SB is energized. This sends pilot pressure oil to the return side of the injection cylinder backing off the screw and decompressing the material. The amount of decompression is controlled by the “suckback” timer. The suckback valve is also used to return the screw without preplasticizing material. Its maximum pressure is controlled by the spring of check valve 4.

When the cycle calls for injection, the main control valve is shifted to “inject” sending oil into the injection forward end of the cylinder through check valve 5.
This brings the screw forward forcing the material out of the nozzle. The gauge valve has also shifted to the injection forward side connecting the injection pressure gauge to the circuit. Two injection pressures are obtained with valves 7, 8, and 9. With solenoid 8 deenergized relief valve 7 controls the maximum
pressure. When solenoid 8 is energized by a timer or a limit switch relief valve 9 is attached to the circuit and now controls the pressure at a value less than relief valve 7. When the injection is complete all solenoids are deenergized, preparing for the next cycle.
CHAPTER 7

Electrical Mechanisms and Circuits

Alternating current is supplied in a three-phase system; AC generators are wound with three armature circuits spaced 120 electrical degrees apart, producing currents and voltages that are separated by this amount. They are transmitted at high voltage and reduced to the plant voltage by transformers (1).

BASIC INSTALLATION DATA FOR ELECTRIC POWER

The two types of power connections are the delta and wye. The delta connection has the three transformers connected one to the other to form a triangle. Power is taken from each of the three connections. It is a three phase, three wire system where the voltage between each pair of line wires is the actual transformer voltage. The line voltage is in phase with the voltage across any one winding. The line current is either 30 or 150° out of phase. By adding vectors, we find that the line current is the $\sqrt{3}$, or 1.73 times the individual or single phase current.

The wye connection (Figure 7-1) is almost always found in molding plants. It is a three phase, four wire system with a neutral grounded line. The current rather than the voltage is in phase. The single phase voltage $(A, B, \text{ or } C)$ to neutral is equal to the three-phase voltage $(A - B, B - C, \text{ or } A - C)$ divided by 1.73. This provides two voltages from the same system. Any unbalance in the system (such as caused by resistive heating) is carried by the grounded neutral. The 208Y/120-V system supplies 120-V single phase for lighting and 208-V three phase for small motors. Where possible, this voltage system should not be
used for molding equipment as the higher voltages are more economical. The 460Y/265-V and 480Y/277-V are virtually the same, the difference being in the internal connections of the standard single phase 240-V transformers. Since the 277-V single phase is directly usable with fluorescent lighting loads, and the 460/480-V for three-phase motors, it fits well for molding plant operation; 120-V is provided by transformers.

The power in three-phase systems is

\[
P = \frac{1.73 EI \cos \theta}{1000}
\]

(7-1)

Where
- \( P \) = power (kilovolt-amperes, KVA)
- \( E \) = volts
- \( I \) = current
- \( \cos \theta \) = power factor.
Installation Costs

The higher the voltage the lower the current required for a given power output (see Eq. 7-1). The size of the copper wire is a function of the number of amperes to be carried. Therefore, going from a 208-V to a 480-V circuit reduces the copper requirement to less than half. It also requires smaller conduit. Because of this and lower equipment costs, motor installations for lower voltage systems cost more. The cost of installing a 208-V system is approximately 55% higher than a 480-V System.

For other reasons as well, it is desirable to use the higher voltage system (2). If a plant has a 208-V system and needs additional wiring capacity, consideration should be given to raising the voltage. If the higher voltage was used in place of the 208-V system no new installation would be necessary. Almost all large motors used on molding machines can operate at the higher voltage.

Ratings

The difference between the nominal system voltage rating and equipment nameplate rating can be confusing. The system voltage is the transmission voltage under no load and is decreased by the voltage drop through the transformer and transmission system. For example, a single phase 120-V system will have a 115-V motor and control rating and a 120-V heating device rating. Similarly a 480Y/277 system will have a 440-V motor nameplate rating.

Power Factor

The cosine $\theta$ of (7-1) is the power factor. It is an indication of the efficiency of the electrical system. Induction equipment requires magnetizing power to produce the flux needed for its operation. This reactive power does no useful work and is measured in kilovars (kvar). The real or working power is measured in kilowatts (kw). The power factor is the ratio of the power actually used (kw) as measured by a watt meter, divided by the apparent power or product of the volts and amperes. In a resistive circuit (heating bands, ovens, lights) there is no inductive load so the power factor is unity. A 40-hp induction motor has a full load power factor of 0.89 and a half load power factor of 0.83. Since motors on injection molding machines often run at less than half a load, the power loss is significant. It requires the unnecessary transportation of electrical energy. It is counterbalanced by the unity power factor of the heating loads. The power factor of an inductive load can be improved by using a capacitor. It is normally uneconomic to raise the power factor above 90 to 95%. Improving the power factor has the following advantages:

Lowers demand charges by the utility company.
Increases system capacity.
Lower $I^2 R$ losses.
Lowers voltage drop.
Lessens transformer size requirements.

Low Voltage

Low voltage in a system that originally had a permissible voltage drop (2% at full load in feeder circuits and 1% at full load in branch circuits) can be caused by the addition of too much equipment, decrease in power factor, and a drop in voltage from the utility. Unfortunately the latter is quite common in major industrial areas such as New York City. Extra equipment requires more current in the distribution line. Since the conductor's resistance is constant, the larger the current the higher the voltage drop. These $I^2 R$ losses cause the conductor to heat, increasing the line resistance and aggravating the voltage drop. Some cures follow:

Run more copper. A machine or group of equipment can be wired directly to the power source.
Increase the power factor. This will reduce the reactive current in the lines.
If possible, raise the voltage from 208 to 480. This will almost double the current capacity of a given conductor.
Change the transformer taps to offset the drop in voltage.

Low voltage adversely affects the performance of induction motors, heating devices, and solenoids. The torque of the motor, the output of the heater, and the pull of the solenoid vary as the square of the voltage. A 10% voltage drop will therefore decrease the torque 19%, the wattage 19%, and the pull of the solenoid. With a 10% voltage drop the temperature of the motor rises 6 to 7°C. Most solenoids are designed to operate successfully at 15% under voltage. When equipment is working close to capacity, voltage drops may prevent molding. For example, a 19% drop in torque might prevent an electrically powered screw from turning. A 10,000-W heating system will deliver 8100 W, which might not be enough to operate an oven. Similar problems could occur with the heating bands of a cylinder and with hopper dryers. An inexpensive recording voltmeter is useful in locating this problem.

PROTECTIVE DEVICES

The purpose of the electrical system is to provide uninterrupted power to the operating devices. The system is designed so that short circuits and overloads are isolated, allowing the rest of the system to remain in operation. Fuses, circuit
breakers, safety switches, or their combinations provide this protection. The protection of the main feed system and the secondary distribution lines are beyond the scope of this book. The following discussion relates to the protection of machines, individual devices, and circuits.

Fuses

A fuse is a device which protects a circuit by melting open its current responsive element when an overcurrent or short circuit passes through it. The plug type is rated up to 30 A and not used on systems over 125 V. They screw into standard sockets or special coded sockets which prevent insertion of the wrong size fuse.

Cartridge fuses up to 60 A have the ferrule-type connection. Above 60 A, they have knife blade-type contacts. They are made either for one time use or have provisions for replacing the fuse links. While renewable fuses are initially more expensive, the low cost of the links make them economical. Several different link ratings fit in the same cartridge. Both the outside of the cartridge and the panel should be clearly marked with the proper link rating.

Both type fuses are made either with single elements for short circuit protection or double elements for overload protection. A motor winding may draw enough current to damage its insulation, but is not enough to open the short circuit element of the fuse. The overload protection consists of a copper heat sink, which will melt an alloy, permitting a spring to pull a connection which opens the circuit. This type unit will permit the normal high starting currents of a motor but will open on a 35% continual current overload.

Some types of electrical equipment, such as meters, transistors, diodes, and semiconductors are damaged by even slight overloads. A current limiting fuse which interrupts in milliseconds is used to stop or limit the buildup of short circuit currents that can damage these devices.

Circuit Breakers

A circuit breaker is a device which will automatically interrupt the circuit when abnormal amounts of current in excess of its rating are applied. It can be reset and used again as contrasted with fuses which have to be replaced. The circuit breaker has a trip unit which is activated by the overload; contacts which break, opening the circuit; arc chutes which contain the arc caused by the circuit breaking; and an operating mechanism energized by the trip unit. A thermal trip unit has a bimetallic element which heats up as current flows through it. It bends or deforms unlatching the mechanism which opens the main contacts. A thermal-magnetic trip has the same bimetallic unit to which is added a magnetic mechanism activated by the magnetic field created by the current. An hydraulic-magnetic trip has a solenoid with a dashpot time delay element.
Changes in the coil current change the flux which causes the iron core to move within the coil. The iron core is in a silicone fluid which acts as a dashpot. As the core moves into the coil, it will reach a point where the magnetic force is strong enough to activate the tripping element. The time delay is a result of the dashpot effect. On extreme overloads or short circuits the coil itself develops enough magnetic field to activate the trip.

As with fuses, circuit breakers can have both instantaneous and time delay characteristics. The tripping curve can be adjusted to the application. Rapid acting circuit breakers are available for sensitive equipment although they do not open as quickly as special fuses.

Switches are used to disconnect a circuit element so that it can be handled safely. They are used as on-off devices with noninductive loads such as ovens and heating cylinders. Motors are controlled by starters. Switches in motor lines are best used when the motor is not in operation.

**CONTROL RELAYS**

The purpose of a relay is to activate control devices in their proper sequence. It is done by opening or closing contacts. A control relay is a device that is operated by a change in the condition of one electric circuit. This causes the operation of other devices in the same or other circuits. They do not control power consuming devices such as ovens, motors, and lights, except for solenoids and motors that use less than 2 A. There are many different types of relays including solid-state, reed, mercury wetted, and armature. The electromechanical relay (Figure 7-2) is found on molding machines and is discussed here.

Control relays contacts are made of silver or silver alloys and should only be cleaned with fine emery cloth and never with a file. The contact arrangements follow:

1. Normally open (NO),
2. Normally closed (NC),
3. Overlapping.

Item 3 is a combination of two sets of contacts actuated together and arranged so that the contacts of one set open (or close) after the contacts of the other set have closed (or opened).

The poles on which the contacts are mounted can be:

1. Fixed, cannot be changed from NO to NC or NC to NO.
2. Convertible, contacts can be readily changed from NO to NC, or NC to NO.
3. Universal, which has one each NO and NC contacts on a pole.
Figure 7.2 Four pole electromechanical contact relay (Courtesy of Allen Bradley Co.).
For practical reasons there are rarely more than six poles on a relay. There are many different types of relays. For example, when two large motors are to be started together it is desirable to start one slightly after the other to reduce the feeder in-rush current. This can be done with a time delay relay. The three ways to do this are pneumatic (dashpot), thermal (bimetallic strip), and electronic (resistor and capacitor). Latching relays remain activated until the latch (mechanical or magnetic) is released. Overload relays are used on motor contactors. Relays are also available that are monitored by frequency phase changes and voltage conditions.

Relay Activation

The poles are activated by an electromagnetic device consisting of a stationary iron core and coil and a movable relay magnet or armature, that is composed of layers of laminated high-permeable steel. The armature is attached to the moving contacts of the relay. When the coil is energized the armature will move up activating the relay. When the coil is deenergized gravity and possibly a spring will return it to its original position, deactivating the contacts. In 60-Hz circuits, the magnetic field will be zero 120 times each second as the current alternates. This will create hum and chatter which is objectionable mechanically and esthetically. A shading coil is used to establish a lagging magnetic field to keep the armature in position all the time. If a relay chatters or buzzes the shading coil should be checked.

Thus it is obvious from the construction of the relay that the coil and each contact are separate circuits and can use different voltages. For safety reasons, the control circuits on molding machines should be 120 V with one side grounded. Figure 7-3 shows the JIC symbols for electrical devices. The relay coil, for example, is a circle, and the normally open contacts are two vertical lines with an oblique line added for the normally closed designation.

Relay Failure

The major cause of relay failure is dirt which causes improper seating of the armature or plunger, with corresponding overheating of the coil and its eventual burn-out. Dirt also prevents the proper seating when closing and opening of the contacts causing excess arcing and rapid contact failure. If a relay does not function it should be mechanically checked for loose or broken wires. The armature should be moved by hand to see if the circuit functions. If it does, the fault lies in the coil. This can be checked by disconnecting it and applying an outside source of current. If the fault is mechanical and is not cleared up by an air blast, the relay should be disassembled and inspected.
CONTACTORS

Contactors are devices for repeatedly establishing and interrupting an electric power circuit. They are used for controlling motors, ovens, heating cylinders, and lights. They are essentially similar in construction to relays excepting they have heavier power ratings. They are combined with various overload protective devices selected for the appropriate use.
Overload Protectors for Contactors

For example, contactors for ovens or heaters only require fuses or circuit breakers. Overload protection is required for motors, which prevents overheating of the motor caused by excessive current.

Magnetic-type overload protectors have a coil connected in series with the motor load and a plunger which will trip when the motor current flowing through the coil develops a strong enough magnetic field to move the plunger and open the motor contactor coil. This operates instantaneously when the tripping current is reached. Since the inlet starting current of the motor is much higher than the full load running current, a dashpot type time delay is included. This type motor protection is inferior to the thermal and only used when ambient temperatures make thermal controls impractical.

Thermal overload protectors use either bimetallic materials or low melting eutectic alloys. A heater coil in series with the motor winding is placed near a bimetallic disk. When the coil overheats it will cause the bimetallic disk to pop, mechanically opening the motor contactor coil, stopping the motor. When the disk cools, it will pop back closing the coil and restarting the motor. This automatic reset makes it undesirable for molding machine control.

For totally enclosed motors where a locked rotor condition causes rapid heat buildup, thermal overload protectors are installed in the motor housing. It is evident that this type of thermal overload protection will not protect the motor from short circuits. This is done by adding fuses or circuit breakers in the line.

Mercury type contactors are used in heating-load applications. They consist of hydrogen filled glass tubes, containing contacts; a ceramic-lined, stainless steel plunger; and mercury. The plunger (which is weighted in the NC unit and floating in the NO one) acts to raise or lower the level of the mercury, making or breaking the circuit. It is energized by a coil surrounding the tube.

The limitations are that they must be mounted vertically, cannot be mounted on a vibrating machine, and are subject to the breaking of glass. The advantages are no moving parts other than the plunger; no contact pitting; contacts unaffected by water or atmospheric contaminants; no mechanical banging; no 60-Hz hum; and little maintenance.

ELECTRIC MOTORS

Information on the theory and operation of motors is readily available elsewhere. We briefly discuss them from an operation and maintenance (3) point of view.
Motor Failure

Motor failure should be thoroughly investigated, since a modern motor, properly maintained, should outlast the useful life of the machine. If a motor does not function electrically the fault is in the power circuit, the control circuit, or the motor. The first thing to do is to measure the surface temperature of the motor with a pyrometer. Previous maintenance records should indicate its normal operating temperature. If it is within this range, the indications are the motor was not overloaded. Mechanical or electrical faults will cause overheated motors.

Mechanical Faults. Mechanical causes would include the bearings; a failure of the fan (if there is one in the motor); dust, dirt, or plastics inside the windings; and an overload caused externally, such as a jammed grinder or hydraulic overload. Mechanical breakdowns are usually heralded with motor noise. Although a noisy motor can also be caused by single-phasing (one of the phases is not receiving current). This condition can be checked by stopping the motor; if it will not start again the problem is electrical, not mechanical. The motor can also be checked by using a clip-on ammeter on each leg.

Electrical Faults. The first step in locating an electrical fault is to use a voltmeter on the line side of the fuses or a circuit breaker. If power is available, the fault is not in the main feeder. Voltage is checked on the line side of the motor contactor. If there is no voltage, the fuse or circuit breaker has opened. The disconnect switch between the feeder lines and the motor is opened isolating the motor power circuit. The fuse or circuit breaker faults are corrected. An ohmmeter is then connected to each side of the contactor and ground. The ohmmeter is also placed between each pair of legs. The short circuit will be readily located. If it is in the motor it is usually a burned insulation on the stator winding and is readily smelled. This should not happen with proper motor protection. After the motor is repaired, the overload control system must be thoroughly investigated. If no grounding is located, it pays to start the motor again under no load. Occasionally fuses and circuit breakers go with no apparent fault. One should be certain the circuit breaker is functioning correctly.

If voltage is available on the line side of the contactor, the fault is in the contactor, control circuit, or motor. If the contactor is momentarily closed manually with the power on, and the motor starts, the fault is in the contactor or control circuit. The control circuit fuses are checked. The quickest way to check the contactor-coil is to disconnect the two leads. Then another source of current with the same voltage is connected to the coil through a switch. If the contactor does not operate the coil is replaced. If it operates the fault is in the remainder of the control circuit. The thermal overloads may be faulty and can be easily replaced for checking. The electrical circuit diagram of the machine is followed and the offending unit or wire will be found. Once the motor is running a clip-on ammeter on each leg will tell if each winding of the motor is
drawing approximately the same current. The variation should not exceed 5%. If not, the motor should be stopped and checked.

If the motor is faulty it is wise to call in an experienced electrician to confirm the diagnosis and locate the reason for failure.

*Maintenance Prevents Motor Failure.* Dirt is the prime cause of motor trouble. It acts as an abrasive and breaks down the insulation of the stators. Because of the oily and dusty nature of the molding plant, it will settle in the motor and tend to act as a heat insulator preventing full removal of heat as designed into the motor. Cleanliness of the motor and its surrounding area is important and part of the daily maintenance schedule.

The motor should be checked weekly by feeling the bearing housing and the motor itself for excessive heat and vibration. While the hand is not an accurate temperature indicator, experience will soon show when a motor is hot. At the same time, visual inspection of the couplings is made. Any unusual noise, smell, vibration, or any unusual sign requires the motor be shut down immediately and the cause determined.

The current in each winding should be checked with an ammeter monthly. Special ohmmeters are available to measure the insulation resistance between the field windings and ground. The severe service of motors in the injection plant require lubrication of the bearings. Motor manufacturers have excellent service manuals which should be read and followed.

**CONTROL SWITCHES**

Control switches are devices for making, disconnecting, or redirecting an electric current. They are distinguished from power switches such as circuit breakers by their function and small size. They are designated both by what they do and how they operate. If a switch has one pole or contact it is a single-pole switch. “Contact” means the ability to make or break a circuit. If it has two sets of contacts, it is a double-pole switch. If it makes and breaks only one contact, it is called a single-throw switch. If in making one contact, it breaks another, or in breaking one contact makes another, it is called a double-throw switch. Therefore a double-pole double-throw (DPDT) switch makes and breaks two independent circuits. Each pole has a normally open and normally closed contact. The switch could have a center or off position where the input lines are isolated. Switches may have the following actions.

1. *Momentary action.* When an operator (human, mechanical, or electrical) activates the switch, it remains activated only for the time the force is applied. When the force is removed it returns to its original position.
2. **Maintained action.** When activated they transfer the circuit from one set of contacts to another. They maintain this position regardless of whether the activating force is removed, even though the activator may return to its original position. When the switch is activated again the contacts will transfer the circuit to another circuit or back to its original position.

3. **Sequential action.** Two or more sets of contacts are switched in a predetermined sequential order. Some sets might be operated simultaneously and others may actuate more than once in any sequence.

### Switch Activation

Switches are activated in many ways.

**Push-Buttons.** Push-buttons are perhaps the simplest type. They are used on molding machines to stop and start the motor, and in manual operations. The toggle switch is basically a push-button switch with a maintained contact. They are general purpose switches used for lighting, in molding machines and all over the plant. A variation of this switch uses a key instead of a lever to open and close the circuit. It is very useful where it is desired to limit the number of people who can set the circuit which it controls. An example might be switching from semiautomatic to automatic cycle. This can be an important safety measure.

**Rotary Type Switches.** Rotary-type switches are used to transfer circuits. They are primarily used in the molding machine for changes to automatic, semiautomatic, and manual operations.

**Limit Switches.** A limit switch (4) is a means of interfacing position or mechanical motion with the electrical circuit. The contacts are mounted in rugged enclosures and usually consist of one set of normally opened and one set of normally closed contacts. They can be had in up to four-pole configurations. The most common operator is a rotating lever with a wheel at the end. It travels approximately 100° with a 2° movement required for operation. Other operators are top push-buttons, top push-rollers, side push-buttons, and side push-rollers. Oil tight enclosures should be used on molding machines. They are widely used on molding machines, being found in safety control circuits, low pressure closing, platen speed, injection control, and mold safety circuits.

**Proximity Switches.** Proximity switches sense and indicate the presence or absence of a moving or stationary object without physical contact. The types primarily used on molding machines operate on the principle of changing the balance of magnetic fields causing contacts to operate. Their primary use is in the low pressure closing systems of toggle operated machines.

**Snap-Acting Switches.** Snap-acting switches work on a cantilever beryllium-copper spring system. The action is positive, regardless of the speed of the
operating force. Once the operating position is reached it snaps over rapidly in less than 0.005 sec. The contacts are usually single-pole double-throw, small in size, rugged, dependable, and exceptionally versatile. Actuated by plunger, pin, lever, push-button, toggle, one-way dog, and wire, they come in all types of enclosures and are used as limit switches. These devices are of great assistance in designing automatic fixtures and equipment and safety devices in molds.

**Pressure and Temperature Actuated Switches.** These switches work on the principle of mechanical action induced by a movement resulting from temperature or pressure changes. In temperature switches, the switch member might be opened by the action of a bimetallic element, the movement of a bellows, the movement of a capillary, or a change in pressure due to the temperature of certain gases. In pressure switches, the pressure usually operates a bellows. A transducer is a pressure switch where the pressure changes the electrical resistance of a circuit.

**TIMERS**

All industrial processes are related in some way to time. A timing device will measure a predetermined interval of time and, at its conclusion, operate a device (5).

**Types of Timer Elements**

The timing elements can be classified into six groups.

1. Mechanical.
2. Thermal.
3. Dashpot.
4. Electronic.
5. Solid state.

**Mechanical Timers.** These timers consist of a spring, escapement and actuator, and switch. The spring is wound and its unwinding rate is controlled by the escapement, similar to a watch. At the end of a preset interval the actuator controls a switch. They are low in cost, unaffected by electrical conditions, noisy, and have relatively limited operating life. They are occasionally used for auxiliary operations such as timing a tumbling barrel.

**Thermal Timers.** These are of the bimetallic and expansion type. The latter uses the principle that metal expands with heat. It mechanically amplifies this motion to throw a switch. Aside from bimetallic elements used on motor controls, thermal timers are not used in the molding plant.
Dashpot Timers. The timing of dashpot timers is controlled by the rate of flow of air or a fluid through a fixed or adjustable orifice. When the coil of a solenoid is energized, it moves at a rate controlled by the pneumatic or hydraulic flow. They are not often used on molding machines.

Electronic Timers. Electronic timers use R-C (resistance-capacitor) circuits for timing. The control element can be on a transistor, a transistor and a silicon-controlled rectifier (SCR) combination, or a unijunction transistor (UTJ) and SCR combination. The R-C timing is based on the discharging action of a capacitor through a resistor. The time of discharge will depend on the size of the resistor. The timing range is usually limited to 5 min. This timing device can drive an electromechanical relay to operate the timed device, which has the limitation of any mechanical device. Solid state switching can be used, which makes the timing much more expensive. Electronic timers are more accurate than motor-driven ones, but voltage and temperature changes can affect them adversely.

Solid state timers count the pulses of the 60 cycle alternations of the current. Even though they are more expensive their extreme accuracy and reliability has resulted in their growing use in molding machines.

Electric Motor Timers. Almost all timers used on molding machines are driven by a small synchronous electric motor attached to a gear train. Because of the remarkably accurate frequency control of modern power systems, such timers are exceptionally accurate. They can be classified into cycle timers and reset timers. They are activated by the result of another physical set of conditions, such as a limit switch, push-button, pressure or temperature switch, or another timer. Certainly, not every part of the injection molding process is or should be controlled by timers. Untimed motions are those which are variable, and whose usefulness is determined by the completion of a motion or action. This can either start a timed action or another similar untimed action. An example of an untimed action is the return of a plasticizing reciprocating screw, which is stopped by a limit switch at a given position. Another example is the closing of the platen which may start the overall clamp timer and the injection forward motion.

Cycle Timers

A repeating cycle timer, once the program is set and the motor circuit closed, will continually repeat itself without interruption. If it is stopped, it will start again at precisely the same point where it is stopped. The mechanism of such a timer is a synchronous motor to which is attached a cam or cams, which mechanically open and close switches. The cams can be adjustable. When the adjustment is readily made by a dial they are called percentage timers. They keep the switch on for a given percentage of the cycle.
One of the most useful repeating cycle timers is a time-switch clock. It has a motor which operates a series of adjustable cams that trip an “on-off” switch. It has a 24-hr cycle, but provision for skipping days. These timers are used, for example, to turn on the heat for heating cylinders and ovens for start-up at the beginning of a week.

A time meter is not a timer in the sense that it does not perform the function of activating a circuit, but instead is a meter which totalizes the length of time electric current is flowing in a given circuit. It is basically a synchronous motor attached through a gear train to an indicating dial. These dials read in minutes or hours and are useful in recording interval operations such as the length of time a heating element of a cylinder is in operation.

Automatic Reset Timers

Reset timers start from a zero “reference point,” measure time for a predetermined time interval, trip its contacts, deactivate the motor and clutch, and reset itself to its original zero “reference point.”

A clutching mechanism is required. A clutch motor has a gear on its rotor which is separated from the gear train by spring action when the motor is deenergized. When the motor coil is energized, the magnetic field brings the rotor gear into contact with the gear train starting the timer. The gear train must be reset by a spring. The reset time is small for timers used on molding machines. Timers utilizing clutch motors use them to activate a switch. A relay is usually used.

As an interval timer (which limits the duration of an operation), the relay starts the motor and energizes the load at the same time. When it times out, the switch opens the relay coil deenergizing the load and the time motor and resetting the timer.

To be used as a delay timer (which varies the delay between two operations) the relay is activated at the end of the delay period, starting the load. It can also be accomplished by permitting the motor to stall at the end of the cycle.

The second way to operate a clutch is to use a solenoid which is external from the motor. This has the advantage of adding additional contacts energized by the solenoid. A type of timer using this system is a variation of a program timer. Any number of contacts are located from a zero time position. When the clutch is energized the motor will drive the cam timing the contacts. At the end of the cycle the clutch is disengaged and a spring returns the timer to its original position.

Solenoid-Clutch Timer. It is impossible to follow the electrical circuits of molding machines without fully understanding the operation of the solenoid-clutch operated timer. There are three separate positions for the timer. The three switch positions are indicated under the timer contact symbol in the order shown in Figure 7-4.
When clutch is energized
9 — — — 10 Close
6 — — — 8 Close
6 — — — 7 Open

When motor times out
11 — — — 12 Open
4 — — — 5 Open
4 — — — 3 Close

When timer resets—all contacts revert to the diagramed positions

Figure 7-4  A solenoid-clutch type timer in reset position. The three timer positions are (a) timer reset, (b) clutch energized, and (c) timer motor times out.

Figure 7-4 shows the reset position which occurs when the clutch circuit is deenergized. This is the position at the beginning of the operation. When the clutch is energized, the two switches underneath are activated. The timer motor is an independent circuit. When the timer motor times out, the two switches beneath the motor in the diagram are activated.

These contact arrangements permit flexibility in circuit design. Figure 7-5a illustrates how a timer might be connected. In the reset position (shown on the diagram) contacts 3 and 5 are open because 9 and 10 are open. Contact 8 is open, but contact 7 has a completed circuit. Circuit diagrams use two vertical
Figure 7-5 A solenoid-clutch type timer connected for maintained contact (a) and momentary contact (b).
lines on each side of the diagram for the power supply. When the clutch is energized by closing the limit switch, 9 and 10 close, 6 and 8 close, and 6 and 7 open. Thus in the clutch energized position, contacts 5 and 8 are closed and contact 7 is open. It will have no effect on contact 3, which is motor actuated. The motor is started simultaneously with the clutch being energized. When the motor times out 11 and 12 will open stopping the motor; 5 will open and 3 will close. The motor timing out will not affect circuits 7 and 8 which are clutch activated. When the limit switch opens, the circuit will be reset to its original position.

If the limit switch is opened during the timing cycle the timer will automatically reset. This circuit therefore requires a maintained closing of the limit switch. If the starting impulse was a momentary contact, such as through a limit switch, push-button and such the timer can be connected as shown in Figure 7-5b. A momentary closing of the limit switch would energize the clutch and close contacts 9 and 10. They would interlock the clutch keeping the timer activated regardless of the state of the limit switch. The circuit would have to be opened at another place to reset the timer.

HEAT CONTROLS

Heat is used to plasticize material, to dry materials in ovens and hopper dryers, and to control mold temperature. They all use resistant type heaters which are usually monitored by a sensing element which is amplified in a controller. The controller energizes and deenergizes the heaters to maintain the set temperature.

Temperature is a fundamental measurement analogous to voltage in the electrical system and pressure in the hydraulic system. It is a measure of the potential that determines a body's ability to transfer heat energy from itself to another body by radiation, conduction, and/or convection. It cannot be measured directly and is indicated by its results on the physical properties of other materials that are in equilibrium with it.

These properties are the expansion and contraction of solids, liquids, or gases; vapor pressure of liquids; radiation from a hot body; amount of voltage generated when two dissimilar metals are heated (as in thermocouples); and a change in resistance of conductors with temperature (thermistors).

Temperature

Determining a temperature scale is not simple. Lord Kelvin devised a thermodynamic scale which uses the temperature of absolute zero as $-273.6^\circ C$, based on Carnot's reversible heat engine, temperature increments being in direct proportion to increments in the engine's efficiency. International Temperature
Scale in use today is defined by means of seven reproducible basic temperature points and 12 reproducible secondary points. Two basic points are the equilibrium states of ice and water, and water-steam, at atmospheric pressure. The Fahrenheit (F) scale has the ice point at $32\degree$ and the steam point at $212\degree$. The Celsius (C) uses $0\degree$ and $100\degree$. The lowest theoretical temperature, where there is minimum molecular motion, is given in the Fahrenheit scale as $0\degree$. Rankine, (R) and in the Celsius scale as $0\degree$ Kelvin (K). Table 7-1 shows the relationships and provides other useful information. A college or high school physics review book will refresh and provide other information.

The molder should use the boiling point of water to calibrate heating systems. It is not unusual for thermocouple-pyrometer systems to drift $15\degree$F. When heats are set from molding records this difference will cause trouble. The systems should be checked at least monthly.

**Table 7-1. Some useful electrical and temperature information**

\[
1 \text{ W-h} = 3600 \text{ J} \\
= 2655 \text{ ft-lb} \\
= 3,413 \text{ Btu} \\
= 1.3 \times 10^{-3} \text{ hp/h}
\]

\[
1 \text{ hp} = 33,000 \text{ ft-lb/min} \\
= 746 \text{ W} \\
= \text{ about } 1 \text{ KVA (3φ)}
\]

\[
E = IR = \frac{P}{I} = \sqrt{PR}
\]

\[
I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}
\]

\[
R = \frac{E}{I} = \frac{E^2}{P} = \frac{P}{I^2}
\]

\[
P = EI = I^2R = \frac{E^2}{R}
\]

\[
C = \frac{5}{9} (F - 32)
\]

\[
F = \frac{9}{5} (C + 32)
\]

\[
K = C + 273.2
\]

\[
R = F + 459.7
\]
ELECTRICAL HEATING

All cylinders for injection molding thermoplastics are heated electrically, with resistance heaters. Cylinders for injection molding thermosets are usually heated by circulating controlled temperature hot water in a jacket around the barrel. The nozzle is heated electrically. There are several types of resistance heaters such as tubular resistance heaters, cartridge heaters and band type heaters.

Tubular Heaters

Tubular resistance heaters are made by suspending a coiled resistance heating element made of nichrome in a metal tube or sheath. Magnesium oxide powder is vibration packed into this tube, and mica disks on each side seal the powder under pressure and act as insulators for the heating element. The tube is swedged to size to increase the packing density of the magnesium oxide. An induction heater tempers the outside so it can be bent and shaped to form. Tubular heaters come in different diameters with approximately 20 to 40 W/in.² (The watt density is determined by dividing the total number of watts over the available heating surface.)

Tubular heaters on injection cylinders are assembled by bending and forcing them into machined grooves with a soft mallet, and securing them permanently by peening the grooves with a prick punch. When properly applied with good contact surfaces, and not overrated, these heaters can last the life of a cylinder. They are considerably more expensive to install because machining of the cylinder is necessary, and slightly more steel is required to compensate for the grooves. Because of their construction they are unaffected by molten plastic, accidental physical damage, and mechanical separation at the interface. They require no maintenance aside from keeping the terminals tight.

Tubular heaters are cast in aluminum shaped to the outside of the heating cylinder. They are also formed into grooves machined in aluminum bands that fit over the heating cylinder. These have good heat characteristics and low maintenance. Tubular heaters are very useful on the nozzle where there is good chance of hot material accumulating over the heater. This would burn out a band heater.

Cartridge Heaters

These heaters are made with nichrome wire wound on forms with a magnesium oxide type of cement. The heaters are sheathed with copper (primarily used for heating water), stainless steel, and other alloys. Approximately 40 W/in.² are delivered with stainless steel sheaths. The introduction of an iron-chromium-nickel metal has raised the allowable watt density to 400, and these type units are extensively used for mold heating applications.
The successful use of cartridge heaters depends on an accurate fit between it and the hole. The maximum diametrical clearance is 0.004 in. Molybdenum-based compounds which are liquid when cold and solid when hot are used to lubricate their insertion and reduce the effect of the air gap. The IMS Company (Cleveland) (which has pioneered in the development of heating cylinders and associated equipment) has introduced a nozzle with cartridge heaters which give double the heat and much less maintenance than a standard heating band.

Band-Type Heaters

These heaters are made of nichrome wire wound on a form and insulated. The outside of the band is made of a high grade chromium steel. Mica bands use mica insulation and ceramic bands use ceramic. Compound bands have an insulation of a high heat paste inside a formed shell, which is bent to shape before hardening the compound.

Most injection cylinders are heated with band heaters. The maximum heat input which can be used in plastic processing is 30 to 40 W/in.\(^2\). Higher watt densities tend to give poorer control and shortened band life; therefore, band voltages should be specified carefully. A 208-V band on a 220-V line increases the wattage by 21%. It also substantially decreases the heater life. Conversely, using a 220-V band on a 208 line will reduce the wattage but give much longer band life.

In connecting bands copper wire is not used. Special heat resistant alloys which resist oxidation but carry about a third as much current as the equivalent copper wire are used. The current carrying capacity of the wire rather than its size is specified.

A main cause for band heater failure is loose bands. The life of the heater depends on the ability of the system to remove the heat provided. This is best done by good physical contact with the metal to be heated, since air is an excellent insulator and hinders the drawing off of heat from the metal of the heater. The contact of heater bands should be periodically checked, particularly after the installation of a new band. At this time the electrical connectors to the band are tightened. A major cause for band failure is contact with plastic. The plastic melts and gets inside the heater, carbonizing and shorting the nichrome. A loose cover is provided with the cylinder which protects it from plastic and allows enough ventilation to prevent overheating of the band. A totally enclosed heating cylinder, while economical in electricity, is very expensive in short heater life.

The 440-V bands are not often used because the thin nichrome wire does not give good service life. Pairs of 230-V heaters in series are used instead.

The proper way to check resistance heater operation is to use a clip-on
ammeter. A voltmeter will indicate voltage to the terminal but not a break in the wire. Together they can be used to check the wattage of the band.

CYLINDER TEMPERATURE MEASUREMENT

Temperature measurement of cylinders requires the generation of a control signal to a controlling device which maintains the barrel temperature at a predetermined level (5a). Devices used are thermistors, wire wound elements, and thermocouples.

Thermistors

Thermistors are solid state semiconductors that have a high negative coefficient of resistance change with temperature. They have a quick response and can have long probe leads without compensation. Relatively unstable, thermistors are subject to thermal shock. Consequently, they are not often found on molding machines.

Wire Wound Elements

A second sensor uses the principle of the change of resistance with temperature in a wire wound element. This sensor is considerably more sensitive than thermocouples (discussed below). It does not require cold-junction compensation or thermocouple-break protection and eliminates the need for special leads and protection. It is used in a Wheatstone bridge (5b).

The Thermocouple

The universal temperature sensing device for injection molding heating cylinders is the thermocouple (6). When two dissimilar metals are welded together, they will convert heat energy into electrical energy. The amount of energy converted depends upon the metal chosen and the temperature. The two materials used for thermocouples on heating cylinders are made of iron and constantan (60% copper, 40% nickel) or I/C. The wire has been standardized at 20 gauge (0.032 in.). The J-type (used in the molding industry) has 32°F as the reference junction. The emf generated by an I/C thermocouple at 300° is 7.94 mV, at 400° 11.03 mV, and at 500° 14.12 mV. In this range, the increase per °F is approximately 0.0307 mV. Since the reference junction is at room temperature, thermocouple sensing circuits compensate for the change. A DC current is generated, with the positive wire being iron (white insulation) and the negative wire constantan (red colored insulation) and the indicating instrument is a D'Arsonval galvanometer. If the thermocouple is connected with the wrong
polarity on the meter, the pointer will go to the left and off the scale instead of its normal direction to the right.

The thermocouple is protected by steel tubing whose O.D. has been standardized at 3/16 in. The fitting which screws into the heating cylinder has been standardized at 1/8 in. NPT. The two main ways of holding the thermocouple tightly into the fitting are compression types and quick disconnect bayonet types. The standard shapes of thermocouples are straight, 45° and 90° bends. Thermocouple extension wire is 14 or 16 gauge and must match the temperature-emf characteristics of the thermocouple. The wire, in effect, transfers the reference junction from the thermocouple to the meter or controller. These meters should be protected by iron conduit as stray electrical fields can affect their accuracy. In time, thermocouples will deteriorate and spares should be available. Unfortunately the need for replacement will not be indicated until there is a processing failure.

How to Check the Thermocouple

An excellent way to check the system is to immerse the thermocouple in boiling water. An inexpensive testing unit can be built consisting of a small pot and a heater for boiling water in a glass, permanently mounted. These units can be brought up to the machine and a thermocouple inserted, without disconnecting it from the circuit. If the system is accurate at 212°F it is most likely good throughout its range. Other standards are pure tin in equilibrium at its melting point (449.4°F) and pure lead in equilibrium with its melting point (621.2°F).

The system can be checked at different temperatures by putting the thermocouple in a calibration bath on a hot plate. A stirrer keeps the liquid in equilibrium. An accurate mercury thermometer next to the thermocouple will give true temperature readings.

The most accurate way to check a thermocouple (through not the control system) is to use a potentiometer connected to the thermocouple. The millivolt output is measured and should agree with the value given on standard charts for that temperature.

TEMPERATURE CONTROLLERS

There are two ways of using the current generated by the thermocouple to indicate temperature. One method is the electronic way which uses a Wheatstone-bridge circuit. The second uses a millivolt meter.

Wheatstone Bridge Circuit Indicator

A known voltage determined by the desired temperature is applied to one side of
the bridge to balance the unknown voltage from the thermocouple. When the bridge is balanced, no current flows from the points of the bridge and the system has reached its set temperature.

This system does not always use a meter for control, although sometimes meters are used to show the operator the barrel temperature. Other instruments just have an on-off light indicator. Still others have a meter which indicates the number of degrees deviation above or below the set temperature.

The Millivolt Meter Indicator

The second method of using thermocouple output is to drive a D'Arsonval millivolt meter. Attached to the pointer is a small lightweight vane. One manufacturer uses the vane to interrupt the light in a photoelectric system. Another uses the vane to change the inductance of an oscillating circuit when it moves between two coils. The phototube assembly, or oscillator coils, is mounted on the indicating pointer which is manually set for the desired temperature.

Temperature Control

A thermocouple attached to a portable galvanometer is called a surface pyrometer. It is indispensable for measuring mold temperatures, motor temperatures, and other solid surfaces. Probes can be had to be inserted into the molten plastic to measure its temperature.

By means then of the thermocouple, galvanometer, and vane on the indicator, the controller can be so activated that heat will be called for when the temperature is below the point set manually on the pyrometer and turned off when the indicator is above the set point. This on-off type controller is not satisfactory for molding. If we examine the nature of cylinder and resistance heating and temperature measurement, control methodology will become apparent.

How the Cylinder is Heated

The resistance heater applies heat on the outside of the cylinder. The cylinder, of necessity, has considerable steel to contain the pressures of the plastic material. Therefore, heat transfer from the resistance heaters on the cylinder surface to the plastic material inside the cylinder is not instantaneous. It takes a significant length of time for the heat energy to travel by conduction to the inside wall in contact with the plastic material.

The thermocouple will indicate the temperature at some point in the cylinder wall, probably near the middle. This introduces considerable error too. It can be significantly decreased by using two thermocouples in parallel at each location,
one being as near as possible to the inside wall of the cylinder and the other to the outside wall (7, 8). When the thermocouple(s) indicates that the required temperature is reached, the heat is shut off. However, the heat energy in transit in the cylinder wall will travel through to the plastic and raise the plastic to a temperature significantly above the controlled temperature point. The reverse will happen on cooling.

One of the major advantages of screw plasticizing is the elimination of this cyclic heat input. The screw mechanically shears the plastic and applies heat "inside" the polymer. As soon as the screw stops this thermal input stops preventing temperature override. Since resistance heaters provide a significant portion of the heat, the "heat sink" effect of the barrel is still significant.

**Proportioning Systems.** To improve the on-off type controller an electronically generated proportioning system is used. One way to do this is to feed a small control millivoltage into the thermocouple circuit which will cause the galvanometer to read higher than the actual temperature when the system is calling for heat, and slightly less when the system has been satisfied. Below the level of the proportioning band the heat is 100% on. As it reaches the set point it decreases to 50% on, and until at the far end of the proportioning zone, it is completely off. This is, in effect, averaging the power output, proportional to the deviation from the set point.

In this type of controller, the equilibrium temperature might not be the same as the set point. Automatic reset circuits are used to correct this.

Extruders sometimes require cooling during their operation. It is not inconceivable that this might be required with some of the newer heat sensitive injection molded materials. A three position controller, which has a proportioning heat control band, a neutral band, and a proportioning cooling band, is used for such control.

The galvanometer type instruments use a mechanical relay in the pyrometer to operate the contractor coil of the heat control relay. The closer the temperature is controlled the more often they operate. They are a major source of maintenance. A stuck contactor or pyrometer relay fault will keep the heating bands on continually. This may cause severe degradation of the material and even fires. In many instances the only way to remove the burned plastic is to take the cylinder apart and clean it mechanically. These faults can be very difficult to detect. A useful device is to put one pilot light across the power side of the contactors and another one activated by the contactor coil current. They are mounted side by side under the pyrometer. They should go on and off together. If not the cause should be immediately ascertained. High limit control systems are available which sound an alarm and cut off the heating power when the cylinder barrel reaches a given temperature increment over the set temperature.
**Solid State Devices.** A much better way of temperature control is to use solid state devices totally eliminating the electromagnetic relays (9-11). The output of a galvonometer or potentiometric type control is essentially proportional to the temperature of the barrel. They can be used to drive a saturable core reactor or a silicon-controlled rectifier (SCR). Both these devices will provide a continual amount of current proportional to the temperature of the barrel rather than the on-off type of the proportional controllers. This increases the life of the bands and gives a much better melt temperature control.

**Saturable Core Reactors.** The saturable core reactor works on the principle that AC current flowing through a coil is much less than would be indicated by Ohm’s law. Counter currents are induced in the coil to impede the flow of currents (Lenz’s law). This effect is tremendously increased if an iron core is used. As the current and voltage increase in the coil surrounding the iron core, the flux builds up until the core is magnetically saturated. Then an increase in applied voltage will cause the current flow to increase rapidly. A saturable reactor is one in which the degree of saturation can be controlled independently. This is done with a control winding ultimately driven by the instrument output. Saturable core reactors give excellent results but are being replaced by silicon controlled rectifier units because of certain limitations. They are bulky, have to be matched to the heater load, provide a maximum of 90% power to the heaters, and do not shut off completely when in the circuit.

**Silicon Controlled Rectifier.** Silicon controlled rectifiers solid state controls use the rectifier as a gate, switching from a nonconducting to a conducting state. This can be done in two ways. It is to be recalled that an alternating current changes its polarity with each cycle. A plot of the amount of current versus time shows a sine curve, half of which is above and half below the zero line. One method of gating cuts off the same portion of the current in each cycle. The amount of cut-off depends on the input voltage from the controller. For example, if half the power was required half the cycle would be cut off. While this controls the process very well it also produces transient current interference in the power line which can interfere with other solid state controls. In addition, it cuts off current for part of the cycle and causes a surge in the remaining part. The power source must supply enough current for the whole cycle. This in effect lowers the power factor.

A much better way of controlling the SCR gate is to turn it on and off only when the current output of the power system is zero (when the sine curve reverses). The current is cut off for a given number of cycles depending on the control requirements. Since each SCR picks the “off” cycles at random, the average current drawn from the lines will have a normal 100% power factor.
Basic Limitation of the Control System

All the controllers we have discussed measure the temperature of the steel barrel. We are really concerned with the viscosity of the polymer. Polymer temperatures and pressures in the nozzle are measurable, and will be used as part of the controls in the more sophisticated equipment being developed (12-15).

ELECTRICAL CIRCUITS

Knowledge of the electrical components combined with a thorough understanding of the hydraulic and mechanical action of the molding machine will facilitate following the electrical control circuits. Like the hydraulic circuit, the electrical circuit can be divided functionally (Figure 7-6). A good instruction manual can be very helpful (16).

An electrical schematic drawing will certainly be furnished, although not always conforming to JIC specifications. It is particularly important to have each line numbered on the left and corresponding relay and timer contact identification on the right. Tables listing all of the switches, limit switches, timers, and relays should be drawn as has been done for Figure 7-14. The information should include their location, function, contact location, manufacturer, and part identification. The latter is useful in checking individual components and ordering spares parts and units.

Figure 7-7 shows some methods of controlling solenoids electrically, drawn using JIC symbols (16a). Convention keeps solenoids, coils, and activating devices on the right. The right vertical line is one side of the circuit and the left vertical line the other. The numbers on the left identify each line in the circuit. The numbers on the right show the location of the contacts activated by the coil, switch, timer, and so on. If the number is not underlined the contact is NO. If it is underlined, the contact is NC. In a large drawing it would be otherwise difficult to quickly and completely locate them.

The lower section, lines 1 and 2, show a standard interlocking circuit. Once the NO start contacts are closed, even momentarily, the control relay will remain energized until the NC stop contacts are momentarily opened. Closing the start contacts energizes the coil of the control relay and closes its contacts on line 2. Once this is done there is a continuous circuit through the control relay coil, its NO contact line 2 (now closed), and the NC stop contacts. Momentarily opening the NC stop contacts on line 1 will deenergize the control relay and open the contacts on line 2. These cannot be closed again until the stop contacts are closed again and the start contacts energized. Interlocks are very commonly found in control circuits.
Figure 7-6 Component functions of electrical circuit.
Heat Control Circuit

Figure 7-8 shows a typical circuit for heat control. A timing circuit has been added which permits energizing the heat control circuit so that machines will be ready to operate at the beginning of the first shift of the week.

The timing circuit consists of 24-hr clock 3.* It is normally left running continuously but can be turned off by switch 3. Pyrometer 4 is controlled by the NO contacts 4 of control relay 1. The pyrometer is manually controlled by switch 1. For the timed operation, manual switch 1 is opened and night switch 2

*numbers refer to the lines on the left-hand side of Figure 7-8.
Figure 7-8 Typical pyrometer and heating band circuit.
is closed. When the timer times out its contacts \( T-I \) 2 will close energizing the instrument control relay, CR-1; closing NO CR-1 contacts 4 will energize the pyrometer.

Because the cylinder is below the set temperature, the thermocouple will cause instrument relay CR-2 4 to close. This energizes heater control relay CR-3 6 (for heater H1). The contactors of CR-3 on line 7 and 8 will close sending 220-V power to the heating bands assuming the disconnect switch 7 is closed. When the cylinder is up to heat the thermocouple will cause the pyrometer to deenergize, CR-2, 4 which deenergizes CR-3, 6, and opens the contacts CR-3, 7, 8, deenergizing the heater band. It is to be noted that contactor coil relay 6 operates on 110 V, while the contacts of contactor 7, 8, operate on a different voltage (220 V). The heaters are connected to roughly balance the amount of current drawn on each of the three phases. Unbalanced phase demand is costly in power charges.

Nozzles can be controlled by thermocouples and pyrometers. More often they are controlled by autotransformers. These are very susceptible to overloads and should be protected by special fast acting circuit interruptors. They should never be started at their full load. When the press is shut down they should be turned to zero and turned up gradually. It is not good practice to tie the nozzle band into the control circuit of the first heating bands, as the heat requirements of the two areas are different.

Many machines have the heat control and heating circuits wired into the main machine circuit. This has a serious disadvantage and should be changed. When machines are down for repair and occasionally for mold change, the machines are disconnected. It is desirable to have the heat ready when the repairs are done. The only way to do this, if safety regulations are to be followed, is to have the heating power and control circuits completely independent with their own disconnect switches.

**Motor Control Circuits**

Motor control circuits are shown in Figure 7-9. The overload protectors (OL) will open if there is a sustained "over-current" situation. The fuses will protect from instantaneous faults. The contactor coils close the power contacts that connect the motor to the 220 V or higher power lines and also close a set of relay contacts (1-M, 2-M) which are used in the control circuit.

Lines 1 and 2 show the control circuit for a single motor. When the start button is pushed, the contactor coil is energized. It interlocks through contact \( M, 2 \). The motor will run until either the stop button is pushed, deenergizing the contactor coil; overload (OL-1 or OL-2) opens; a fuse blows in the power circuit; or the disconnect switch is opened. The latter method is not recommended. The stop button should be used first.
Figure 7-9 Motor control circuits.
Lines 3, 4, and 5 show a control circuit for two motors operating together. The motor circuits are shown at the bottom of the drawing. When the start button is pushed, each motor contactor coil is energized through its overloads. The start button is interlocked through a series connection of the two interlock contacts (1-M, 2-M). If either motor contactor coil opens because one of its overload contacts open, the interlock of the start button will be broken, deenergizing both motor contactor coils.

Lines 6, 7, and 8 show a circuit for starting two large motors (which have to operate together) in sequence. This is to prevent excessive inrush currents in the feeder line. When the motor start button is closed, motor contactor coil 1-M, 6 is closed. The start button is not interlocked. Instead the interlock contact of 1-M is used to start a timer T,7. When the timer times out, its contacts T,8 energize motor contactor coil 2-M,8. This interlocks the start button through contact 2-M,7. The light goes on showing that the start button can be released.

If either overload contact of 1-M opens, contactor coil 1-M opens, opening in turn contact 1-M,7. This resets the timer, opening timer contacts T,8, opening the second motor contactor coil 2-M,8. If this or either of the 2-M overload contacts opens, the contactor coil 2-M,8 opens breaking the interlock of the start button, 2-M,7, stopping both motors.

**Low Pressure Closing Circuit.** See hydraulic diagram, Figure 6-39 and Figure 7-10. When the mold closes without any obstruction on the mold

![Diagram](attachment:image.png)

**Figure 7-10** Low pressure circuit with alarm for hydraulic circuit. (See figure 6-39.)
surfaces, a limit switch closes which energizes the low pressure solenoid. This blocks the low pressure relief valve out of the circuit and allows full clamp pressure. If there is an obstruction, the limit switch does not close and the low pressure timer times out. This activates an alarm (bell, light), stops the control circuit, and can be used to shut off the machine.

**Analysis of Circuit.** Machine closes, at which time the cycle start contacts, 2, close. Low pressure timer TD,3 starts timing.

**If there is no obstruction** A- LS1,2 closes energizing the low pressure control relay CR-1,2, which does the following:

1. Closes CR1,1, contacts energizing low pressure solenoid 8,1. This permits full system pressure.
2. Opens CR1,3 contacts stopping and resetting timer,3.

**If mold has obstruction, then the following is true:**

1. LS1,2, does not close and timer TD,3, times out, closing timer contacts TD,4, energizing alarm control relay CR2,4.
2. CR2,5 contacts close starting alarm, 5. Other sets of contacts on this relay could be used to stop the cycle or machine.

**Control Circuit for Automatic Cycling.** Figure 7-11 shows the following:

1. With the selector switch, 1 set at automatic, the returning clamp contacts limit switch LS1,1, within 2 in. of full clamp return, starting cycle delay timer T,1.
2. Machine opens fully, contacting limit switch LS2,2, which deenergizes control relay CR,2. This deenergizes relay contacts CR,4, which will interlock the timer contacts T,3, while machine is forward of LS2. It also resets the control circuit for the next cycle (contacts not shown).
3. Timer T,1, times out, closing contacts T,3, which starts the machine cycle.
4. Clamp ram moves forward permitting LS2,2, to close. This interlocks the control circuit.
5. Machine platen moves more than 2 in., opening LS1,1 and resetting the timer.

**Circuit for Semiautomatic and Manual Control of a Clamping Cylinder Using a Solenoid, Piloted, Three Position, Four Way Hydraulic Valve with all Ports to Tank in the Neutral Position and Two Solenoids Controlled by a Timer.** This circuit is used to operate another cylinder (see Figure 7-12). When the gate is closed, a limit switch is contacted, starting the clamp timer and energizing the clamp relay which starts the machine closing. When the clamp timer times out, its contacts deenergize the clamp relay which sends the clamp back. At full return, a limit switch opens so that both clamp forward and return solenoids are
deenergized, shifting the hydraulic valve to the neutral position. This unloads the pump through the valve to tank.

An additional timing circuit is shown. It is started at the same time as the clamp timer and controls a pair of solenoids, energizing only one of the pair at the same time. This is the standard way of extending and retracting cylinders.

Some cylinders are built so that they must be stopped before full forward stroke. Otherwise the packing bearing and glands may be damaged. An overstroke limit switch LS3,6, is located so that it will open, stopping clamp forward motion before that position is reached.

**Analysis of Circuit — Semiautomatic Cycle.** First turn the three operating switches to semiautomatic.

1. Gate is closed, closing LS1,3. Its safety contacts 6 and cycle start contacts 3 close. This starts clamp timer T1,4, closing its contacts OCO,3, and energizing control relay CR,1.
Figure 7-12 Manual and semiautomatic control of a clamping cylinder – using a solenoid piloted, three position, four-way hydraulic valve with all ports to tank in neutral. Included is another cylinder controlled by a timer and two solenoids, with all ports blocked in neutral position.

a. CR,6, contacts close, energizing clamp forward solenoid 6.
b. CR,7, contacts open deenergizing clamp return solenoid 7.

The clamp moves forward.

2. When clamp ram is fully forward it closes LS4,5, starting cylinder timer T2,5.

a. This closes T2 contacts, 8.
b. Opens T2 contacts 10. The cylinder moves forward.
3. Timer T2,5, times out. (It must complete its cycle before clamp ram returns, because that unloads the pump output to tank through its the open ports in the neutral position).

   a. OOC contacts 10 close energizing solenoid B 10
   b. OCO contacts 8 open deenergizing solenoid A8. The cylinder returns.

4. Clamp timer T1,4, times out, opening timer contacts OCO, 3. This deenergizes clamp relay coil 1 reversing steps 1-a and 1-b. The clamp returns.

5. On full clamp return limit switch LS-2, 7, opens deenergizing clamp return solenoid 7. Solenoids 6 and 7 of the four way valve are deenergized, so the valve shifts into its neutral position which unloads the pump.

6. The gate is opened, opening LS1, 3 which resets timer T1, 4, deenergizing clamp forward solenoid 6. When the clamp returns LS2, 7, opens deenergizing clamp forward solenoid 8.

7. The clamp return also opens LS4, 5, resetting timer T2, 5.

8. Opening the return switch 1 at any time will reset timer T1, 4, opening its OCO, 3, contacts, deenergizing CR, 1, which opens the clamp.

**Manual Operation**

9. Set the switches to manual operation. This removes timer T1, 4 and the contacts of timer T2, 8 and 10, from the circuit.

10. The clamp control relay CR, 1, is controlled by the forward, 1, and return, 1, switches. Closing clamp forward button 1 energizes CR, 1. It interlocks through contacts CR, 2. When the safety gate is closed, LS1, 6, contacts will close. The clamp closes.

11. When the clamp return switch 1 is opened, the interlock contacts CR, 2, opens deenergizing the clamp relay coil, 1, reversing steps A1 and A2. This causes the clamp to open.

12. Similarly, the cylinder solenoids A, 8, and B, 10, are operated by switch contacts 9 and 11.

**Electrical Circuit for Controlling Three Hydraulic Pressures.** See Figure 7-13 and hydraulic diagram, Figure 6-22.

1. With selector switch 1 in "3" position, cycle start contacts 1 are closed by an external source. This starts timers T1, 1, and T2, 2. Since both solenoids A, 4, and B, 5, are deenergized, pilot valve C controls the pressure.

2. Timer T1, 1, times out closing contacts T1, 3, energizing control relay CR, 3, which does the following:

3. Timer T2, 2, times out, opening contacts T2, 3, deenergizing control relay CR, 3, which does the following:

   b. Closes CR, 5, contacts energizing solenoid B, 5 through T1, 3, contacts which are still closed. Pilot valve B controls the pressure.

4. Cycle start contacts 1 are opened (from external source), resetting the timers T1 and T2.

**Simplified Electrical Circuit for a Reciprocating Screw Machine.** See Figure 7-14. Refer to hydraulic diagrams, Figures 6-39 and 6-41. The balance of the circuits can be located in the other hydraulic drawings. The low pressure safety (Figure 7-10) and automatic cycle (Figure 7-11) circuits have been eliminated. The following refers to Figure 7-14.
### Control Relays

<table>
<thead>
<tr>
<th>Location</th>
<th>CR</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Starts clamp forward.</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Energizes extruder run and hydraulic motor solenoids. Energizes full speed solenoid during purge.</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>Starts the extruder and clamp timer.</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>Stops extruder and starts suckback and suckback timer.</td>
</tr>
<tr>
<td>18</td>
<td>7</td>
<td>Controlled speed circuit.</td>
</tr>
</tbody>
</table>

### Timers

<table>
<thead>
<tr>
<th>Location</th>
<th>CR</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>Injection timer.</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Clamp timer.</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Second injection pressure timer.</td>
</tr>
<tr>
<td>13</td>
<td>SB</td>
<td>Suckback timer.</td>
</tr>
</tbody>
</table>

### Solenoids

<table>
<thead>
<tr>
<th>Location</th>
<th>CR</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>A</td>
<td>Clamp forward</td>
</tr>
<tr>
<td>19</td>
<td>SFP</td>
<td>Separates pumps</td>
</tr>
<tr>
<td>26</td>
<td>B</td>
<td>Starts injection forward</td>
</tr>
<tr>
<td>27</td>
<td>G2</td>
<td>Injection gauge</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Second injection pressure</td>
</tr>
<tr>
<td>28</td>
<td>S</td>
<td>Extruder fun</td>
</tr>
</tbody>
</table>

### Semiautomatic Manual Purge- Switch

<table>
<thead>
<tr>
<th>Location</th>
<th>Switch</th>
<th>Purge</th>
<th>Manual</th>
<th>Semiautomatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>
X

1

S-1 Clamp return

SA M P

X A

2

To 16

S-2

Inj. for

3

SA

CR 1

Inj. for

4

S-3

5

S-5

CR1

Opens at full
clamp return

P

6

T3

7

CR4

"L"

CR5

"M"

8

Extruder run

23, 28

Back pressure

9

G-1

CR3

10

Extruder run

7, 9

11

Complete

Closes when extrusion

12

SA

OFF ON

S-4

LS-4

CR5

13

TSB

14

Inj ret.

SB

Suckback SW.

Clamp forward
2, 3, 20

Injection forward
18, 24, 26

Injection timer
3, 10

Injection second pressure
6

Injection second pressure

8

2"L" 2"M"

Extruder stop
2, 12, 15

Time suckback
13,

Suckback

590
Figure 7.14 Simplified electrical circuit for reciprocating screw.
Limit Switches

Location | Switch | Function
---------|--------|---------
1        | 1      | Overstroke protection.
1        | 2      | Momentary gate switch. Starts cycle.
5        | 3      | Opens at clamp return. Resets timers and relays.
11       |        | Closes when extrusion is complete. Stops screw turning. Starts suckback.
18       |        | Closes for controlled speed. Only on during injection.
20       |        | Clamp forward safety. Machine cannot be closed unless gate closes this switch.
22       |        | Clamp speed slowdown.

A description of the circuit follows:

1. Gate closes starting cycle.
2. Machine clamps; pressure builds up, closing pressure switch.
3. Injection timer starts and injection ram goes forward.
4. Injection timer times out starting clamp timer and hydraulic motor which drives screw.
5. Screw turning plasticizes material, forcing screw back until it hits limit switch, stopping the screw, and starting the suck back timer.
6. Suck back starts until timer times out.
7. Clamp timer times out, opening clamp.
8. Fully open clamp opens limit switch which resets timers and machine.

Analysis of Circuit on Semiautomatic Operation. Selector switch set to semiautomatic. Gate is open and all devices are deenergized as diagrammed. Gate is closed.

2. Momentary contacts of LS2, 1, are hit by gate closing, energizing clamp forward control relay CR1, 1 which does the following:
a. Closes CR1, 2 contacts interlocking CR1, 1.
b. Closes CR1, 3 contacts setting injection forward relay CR2, 3.
c. Closes CR1, 20 contacts setting pump separation solenoid 19 and energizing clamp forward solenoid A, 20. **Clamp closes.**

3. Pressure builds up, closing pressure switch contacts 19 which energize the clamp separation solenoid 19 and separate the small holding pump from the large volume pump(s).

4. Injection pressure forward switch contacts 3 close, starts second injection pressure timer T3, 5 and starts injection forward timer T1, 4 closing T1, (OCO), contacts to energize CR2,3 **which does the following:**

   a. Closes CR2, 18, setting controlled speed relay CR7, 18.*
   b. Closes CR2, 26, energizing injection forward gauge solenoid G2, 27, and injection forward solenoid B, 26. Injection starts, which does the following:
   c. Opens LS-4, 11, deenergizing CR5, 11, which opens contacts CR5, 12, resetting suck back timer T-SB 12.

5. **(Concurrently with Step 6) At appropriate location of injection forward travel, limit switch LS5, 18, closes, energizing controlled speed solenoid CR7, 18, which does the following:**

   a. Opens contacts CR7, 21, deenergizing full speed solenoid E, 21.
   b. Closes contacts CR7, 25, energizing controlled speed solenoid F, 25. **Injection forward moves at controlled speed.**

6. **Concurrently with Step 5. Second injection pressure timer T3, 5, times out, which does the following: closes contacts T3, 6, energizing secondary pressure solenoid 8, 6. **Injection proceeds at secondary injection pressure setting.****

7a. Injection timer T1, 4, times out closing contacts T1, 10, energizing extruder run relay, CR4, 10, which does the following:

   a. Closes CR4, 7, contacts energizing back pressure gauge solenoid G-1, 8, connecting back pressure gauge.
   b. Energizes extruder run relay CR3, 7. This closes CR3, 28, contacts energizing extruder run solenoid 28 and hydraulic motor solenoid 29. *(Note: CR3, 23, contacts are only used during purge.*) **Screw turns.**
   c. Close contacts CR4, 9, starting clamp timer T2, 9.

*The large pump is a variable volume, pressure compensated type, whose speed is controlled by solenoids E and F. When E is energized, full volume is delivered by the pump. When F is energized the controlled volume (previously set by the operator) is delivered. When neither are energized, the pump short strokes delivering no volume. At that time in the circuit, the only oil comes from the small high pressure holding pump.
7b. Injection timer contacts T1, 3, open deenergizing injection forward relay CR2, 3, which does the following:

a. Opens contacts CR2, 26, deenergizing injection forward solenoid B, 26, and injection forward gauge solenoid G2, 27.

8. Extruder runs until its backward movement contacts limit switch LS4, 11. The location of this limit switch determines the amount of plastic in front of the screw. Extruder stop relay CR5, 11, is energized, which does the following:

a. Open contacts CR5, 7, deenergizing extruder run relay CR3, 7, reversing steps 7(a) a, and b. *Screw stops turning.*
b. Closes contacts CR5, 15, setting clamp return relay CR6, 15. This is a safety to prevent mold opening while extruder is running. This can happen if extruder slows down (material too viscous, hydraulic pressure drops, etc.), or clamp timer setting is incorrect.
c. If suck back is used contacts CR5, 12, close, which does the following:

(1) Start suck back timer T-SB, 12,
(2) Energize suck back solenoid SB, 13, starting suck back
(3) Suck back timer T-SB, 12, times out opening suck back timer contacts T-SB, 13, deenergizing suck back solenoid SB, 13, stopping suck back.

9. Clamp timer T2, 9, times out closing timer contacts T2, 15, energizing clamp return relay CR6, 15 which does the following:

a. Opens contacts CR6, 1, deenergizing clamp forward relay CR1, 1. This reverses steps 2a-c. It also resets injection timer T1, 4, and second injection pressure timer T3, 5. This would happen in any event, because injection pressure switch contacts 3 would open.
d. Closes CR6, 22, setting clamp opening slow down limit switch LS7, 22. Note that CR1, 20, is open (step 9a); CR2, 18 open (step 9a); CR6, 22, is closed (step 9), therefore, the full speed solenoid E, 21, is controlled by LS7, 22. Controlled speed solenoid F, 25, is deenergized by open contacts CR7, 25.
e. As platen moves back, LS7, 22, is contacted, deenergizing full speed solenoid E, 21. *Machine slows down* moving only on volume of small holding pump.
10. Machine opens fully opening limit switch LS3, 5, which does the following:
   a. Resets clamp timer T2, 9.
   b. Deenergizes relays CR3, 7; CR4, 10; CR6, 15; CR7, 18. Gate is opened and machine is ready for the next cycle.

**Analysis of Manual Operation.** Selector switch turned to manual.

1. Clamp forward is started by closing the gate which energizes clamp forward relay CR1, 1. Contacts CR1, 20, close energizing clamp forward solenoid A, 20. CR1, 1, is interlocked through contacts CR1, 1.

2. Extruder run manual button 8 is closed to turn screw. It must be held. The screw will stop when the carriage contacts limit switch LS4, 11, following the same circuit used in semiautomatic operation.

3. Injection forward button 4 energizes injection forward relay CR2, 3. When button is released, injection forward stops.

4. Injection return button 13 energizes suck back solenoid SB, 13. Screw will return (without turning) under low pilot pressure, to prevent damage. Normally the screw is returned by plasticizing.

5. To open clamp, clamp return button is pushed. Contacts 1 open, breaking the interlock and deenergizing clamp forward relay CR1, 1. Contacts 16 close, energizing clamp return relay CR6, 15, opening the clamp and interlocking through CR6, 17. Relay CR6, 22, also energizes the full speed solenoid E, 21.

**Purge.** Selector switch turned to purge.

1. Switch S5, 5, permits purging while clamp is open, by allowing extruder run button 8 to be energized even if LS3, 5, is open.

2. Switch S9, 24, permits full speed when the injection forward relay CR2, 3, or extruder run relay CR3, 7, are energized.

**TROUBLE SHOOTING**

A plastics engineer dealing with thermoplastics must fully and completely understand the function of machines. Many failures of plastic parts are caused by improper settings or erratic action of the processing equipment. It may be necessary to alter the mechanical, hydraulic, or electrical functions to achieve a certain result. The limitation of the equipment often determines the applicability of the parts.

Most often he is asked to "trouble shoot" a malfunctioning machine. This should not be difficult (17). The speed and efficiency of this recommendations have a lot to do with his status with the operating personnel.

Complete, useful drawings of the hydraulic, electrical, and mechanical parts
of the machine should be immediately available. They should be properly labeled and have sufficient tables, pressure information, and mechanical data, logically and conveniently displayed.

Preparatory to a breakdown, the engineer must understand thoroughly the machine. Probably the best way is to copy the hydraulic diagram. The electrical circuit should be redrawn and a detailed step by step analysis be written. This can be similar to that used for Figure 7-14, or it may be graphed or made in any manner useful to the engineer.

The instruments needed are a voltmeter, hook-on ammeter, pressure gauge, and surface pyrometer. The fault is either electrical, hydraulic, mechanical, or a combination. One should determine what the trouble is by asking the foreman and operators. Any other attempts to find and correct the fault should be ascertained. If possible one should watch the operation until the "trouble" occurs.

Operation of the manual controls, hand operating solenoids, relays, and limit switches can give valuable information. Circuits can be traced for faults by using the voltmeter or ammeter. Electrical and hydraulic components can be visually examined and, if required, disassembled, checked, and repaired. Timers, limit switches, relays, and other parts can be replaced.

All of these things can be done "haphazardly." This is the procedure of the operating personnel not familiar with or unable to use electrical and hydraulic circuit diagrams. The experienced engineer may do some of these things intuitively and rapidly. However, if they do not bring prompt results he will methodically and logically investigate the fault, usually starting from the malfunctioning part.

It is difficult to postulate a universal trouble shooting procedure. We describe tracing the possible causes of a stopped screw in a machine described by the hydraulic circuit Figure 6-41 and the electrical circuit Figure 7-14.

**Stopped Screw Example**

Set the machine controls at OFF and press the motor start button. If the electric motor is operative, set the controls at purge, make sure LS4, 11, is not contacted, and push the extruder run button 8. Check the output shaft of the hydraulic motor and the input and output shafts of the gear reducer. (We eliminate obvious conclusions, i.e., if only the input shaft turns, the trouble is in the gear reducer.) If relay CR3, 7, does not energize, check the control fuses and use a voltmeter across XA and Y. "No" voltage with good fuses suggests trouble in either stop button 1, S1, 1, or S5, 5.

This would be a good time to look at the heat. If the heat has dropped, the viscosity of the plastic might rise enough to prevent the screw turning. A reading of barrel temperatures with a surface pyrometer will check for incorrect readings or temperature sensing by the thermocouples. As far fetched as it might seem,
check the material in the hopper to be sure it is the one specified. Errors, particularly when using reground, are conceivable. If the cylinder heats and material are right, the problem is in the electrical circuit, hydraulic circuit, or mechanical.

Close relay CR3, 7, by hand. If the screw turns, the fault is in the relay coil, the NC CR5 contacts 7, or the extruder run button 8. The offender is easily found by connecting one voltmeter probe to Y, and touching the other probe successively to the XA side of CR3, 7, NC CR5, 7, and extruder run button, 8. If, for example, there is no voltage at “M” and voltage at “L”, the NC CR5, 7, contacts, connections, or wire in that part of the circuit are open.

If relay CR3, 7, is energized, check the extruder run solenoid S, 28, and the hydraulic motor solenoid HM, 29. If they are energized the fault is not electrical. If they are not, the circuits on lines 28 and 29 are checked.

Solenoids S and HM could have been operated by hand before checking the electrical circuit. This is not good practice since there are situations when manually operating a solenoid with electrical faults will cause damage.

If the manual extruder run button 8 started the extruder, the trouble is in the initiator of the automatic circuit, NO CR4, 7, contacts. Relay CR4, 10 is closed manually and the contacts are checked. The following would then be checked in order:

CR4, 10, relay coil.
T1, 10, contacts.
T1, 4, timer.
CR1, 3, contacts.
Pressure switch 3.
S4, 4, switch.
S2, 3, switch.

If the fault is suspected to be hydraulic, the system pressure (and pilot pressure) is checked at the inlet of the inject-hydraulic motor valve. A pressure gauge is attached to the inlet port of the hydraulic motor. If no pressure is available, a gauge at the top blocked port of the “screw on” valve will pinpoint whether the trouble is there, in the main valve, or in the pressure control valve.

If there is pressure going into the hydraulic motor, and unusually high pressure at the outlet port, check valve 3 is blocked. A broken hydraulic motor can be detected by the inability to maintain pressure on the inlet side with the motor stalled. The motor manufacturer will describe test procedures for determining wear (slippage).

If the back pressure valve 6 is stuck closed, there is no place for the returning oil from the injection cylinder to go. The screw may not have enough torque to overcome this 100% back pressure by “churning” the material. Even a low back pressure may be enough to stop screw rotation. Similarly, a mechanical seizing
or stopping of injection return carriage will give the same results.

The final reason for screw stoppage is mechanical, where a "foreign" substance wedges itself between the screw and the barrel. Fortunately, this is rare. The unit must be carefully disassembled and any damage repaired.

**Solid State Controls**

Solid state controls are being used at an increasing rate in the molding machine, particularly for temperature control. Some of the advantages of solid state control, as compared to electromechanical control, follow:

1. No moving parts.
2. Not affected by the environment (vibration and temperature).
5. Faster.
7. Take up less space.
8. Susceptible to computer control.
9. Allow safety to be built in at lower cost.

Some disadvantages follow:

1. Increased initial cost.
2. Unfamiliar to operating personnel.
3. Susceptible to "spikes" and other interferences in the electrical system.

Solid state controls are those which switch without any moving parts. This is done with certain crystalline materials which are electrical insulators or conductors, depending on the input signal. A review of electronics is found in Ref. 17A.

The heating cylinder can be controlled by a silicone controlled rectifier (SCR), which provides stepless control by changing the current to the heating units based on the input of the thermistor or thermocouple. There are two methods of SCR temperature control. The SCR can be fired when the voltage is zero and held for a given number of cycles (zero crossover), or the SCR can be fired for a given part of each cycle (phase angle). The first method is preferred because it will not generate "spikes" in the control system which can cause a malfunction. SCR control of the cylinder increases the accuracy of the control and increases the life of the heater.

Solid state timers are more accurate than the electromechanical timers and are used in sequential switching circuits. NOR/Nand logic systems can be used to program the sequential switching. With electronic control of valves, solid state switching can provide stepless pressure and volume control of the hydraulic