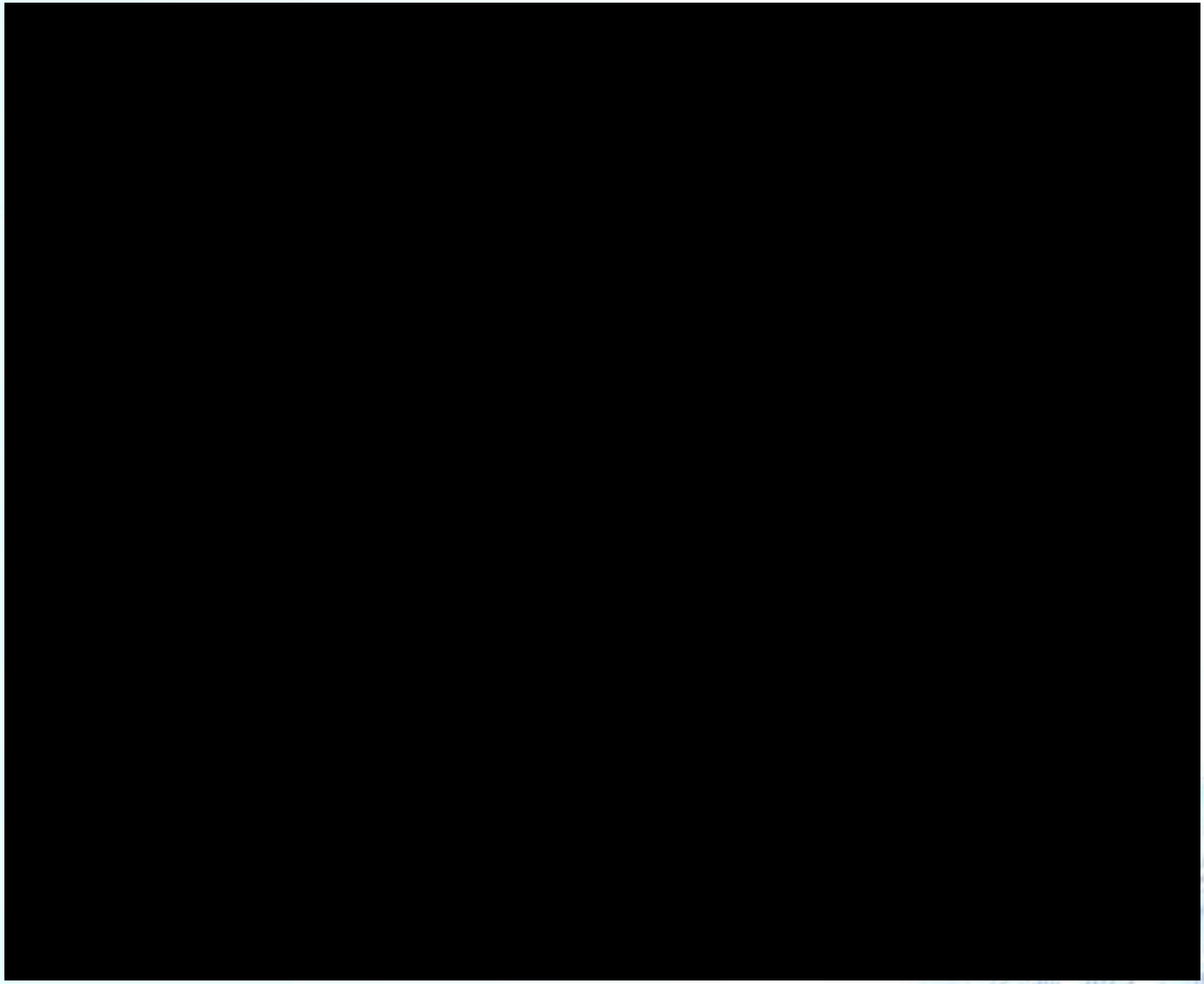
9. Hydraulic Circuit Design & Analysis

- **Description of the operation of hydraulic circuits**
  - drawn using graphical symbols for all components
  - speeds and load-carrying capacities of regenerative cylinders
  - mechanical-hydraulic servo systems
- **Troubleshoot hydraulic circuits**
  - to determine causes of malfunctions
- **Analysis of hydraulic circuits**
  - to evaluate the safety of operation
  - to perform a desired function
  - including the effects of frictional losses
  - the speed control of hydraulic cylinders
- **Fluid Power Symbols**

유압 시스템 기본 구성

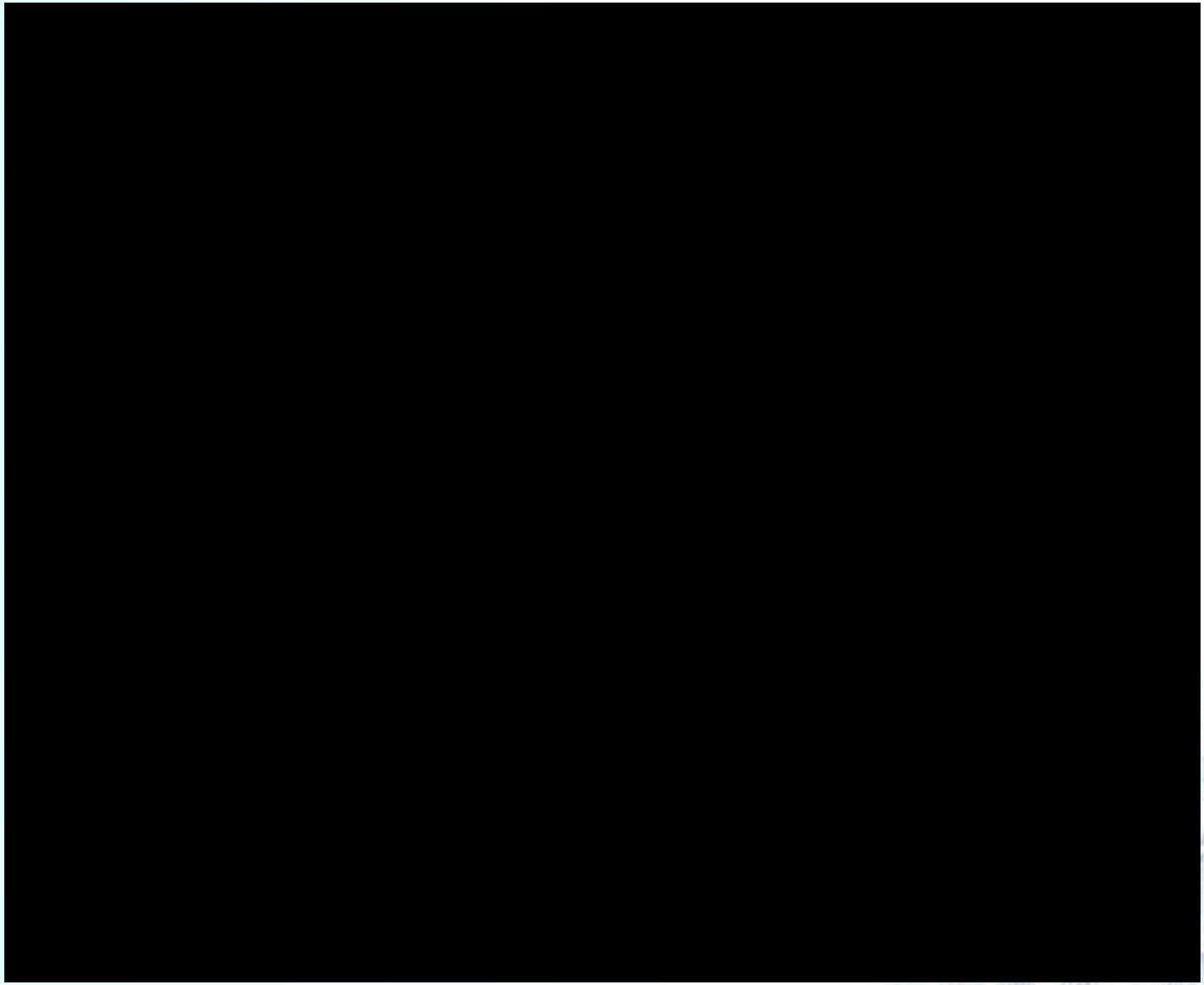


9.1 Introduction

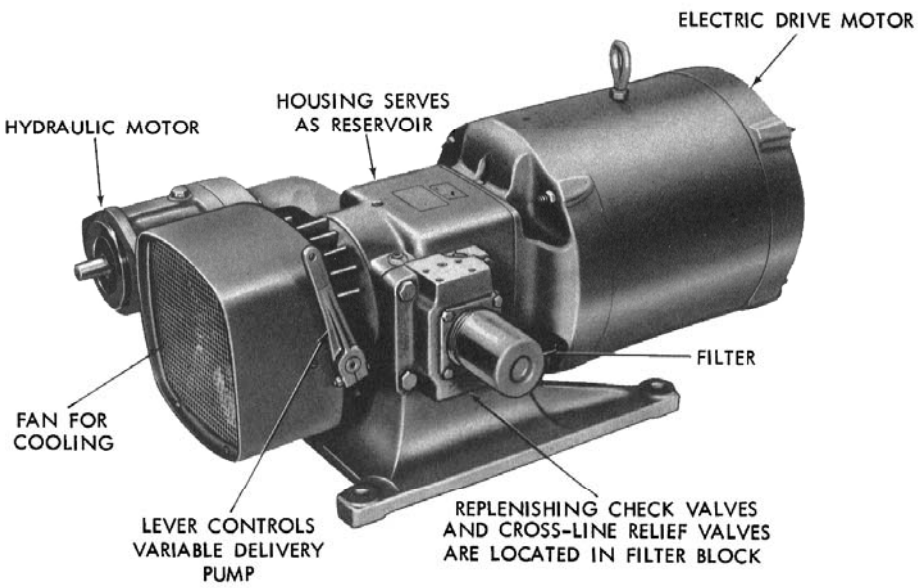
- **Hydraulic circuit**
  - a group of components such as pumps, actuators, control valves, and conductors arranged so that will perform a useful task

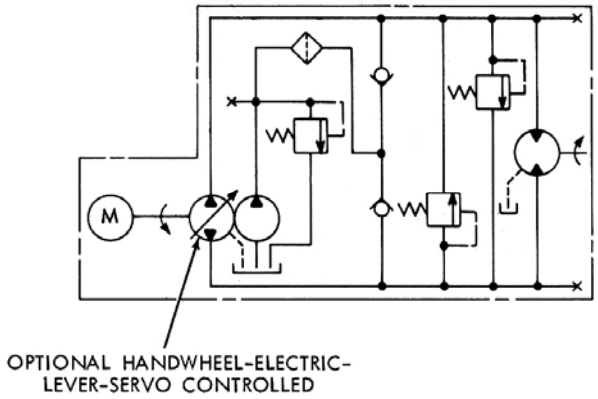
- **Three important considerations**
  - Safety of operation
  - Performance of desired function
  - Efficiency of operation

유압 회로도



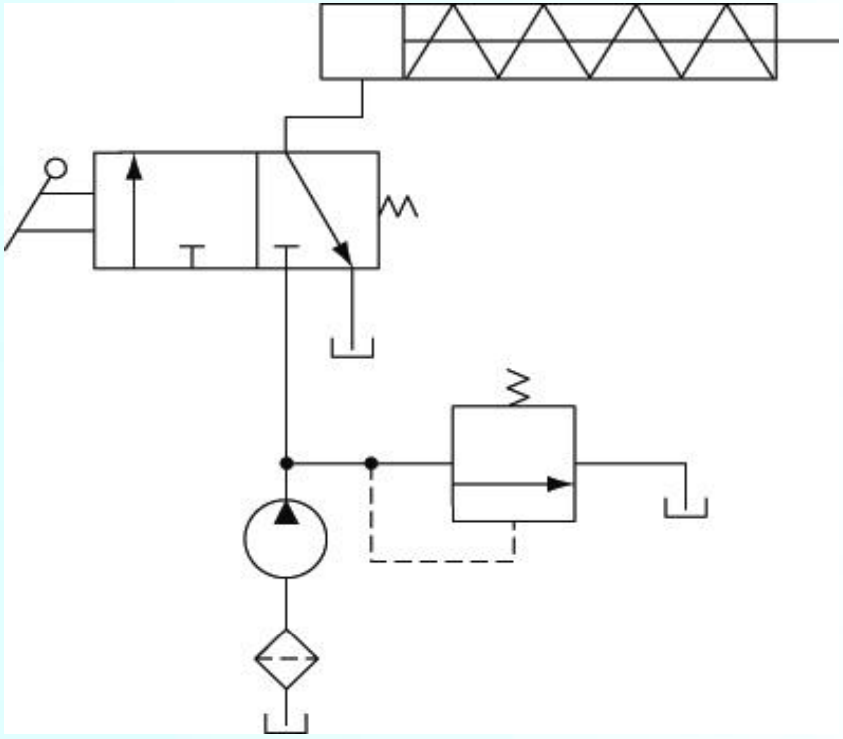
Hydraulic Circuit of Hydrostatic Transmission



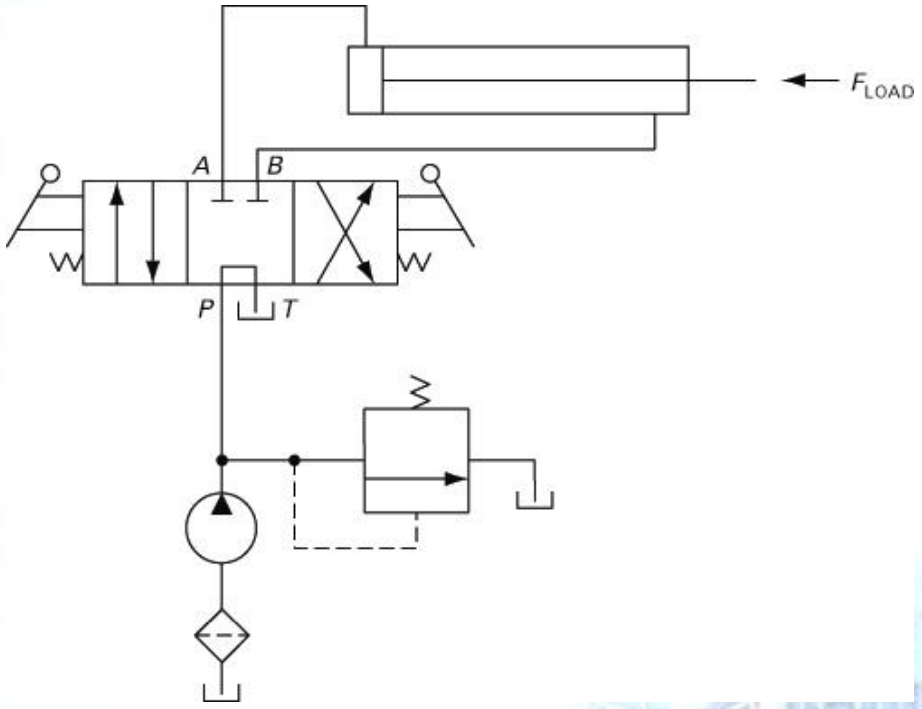


Control of Hydraulic Cylinders

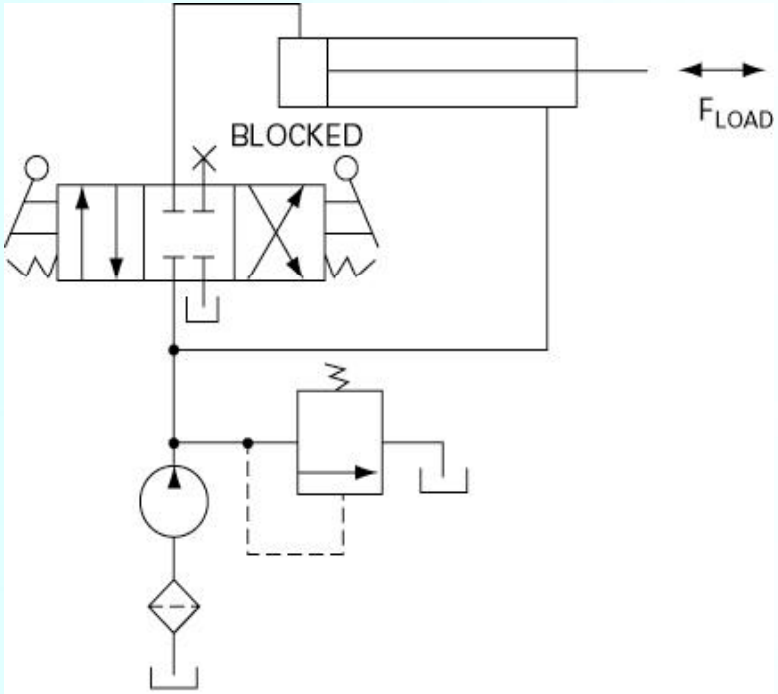
- **Control of single acting hydraulic cylinder**



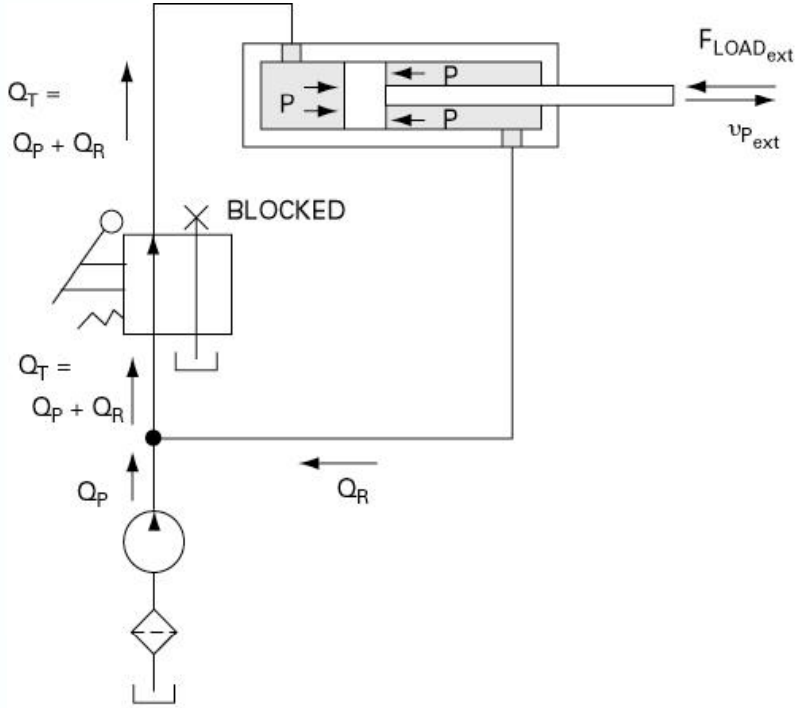
- **Control of double acting hydraulic cylinder**



Regenerative Cylinder Circuit



(a) Complete circuit.



(b) Partial circuit showing flow paths during cylinder extension stroke.

Regenerative Cylinder

- **Cylinder extending speed**

$$Q_T = Q_P + Q_R$$

$$Q_P = Q_T - Q_R$$
$$= A_P v_{P_{ext}} - (A_P - A_r) v_{P_{ext}}$$

$$v_{P_{ext}} = \frac{Q_P}{A_r}$$

- **Load-carrying capacity during extension**

$$F_{load_{ext}} = pA_r$$

- **Ratio of extending & retracting speeds**

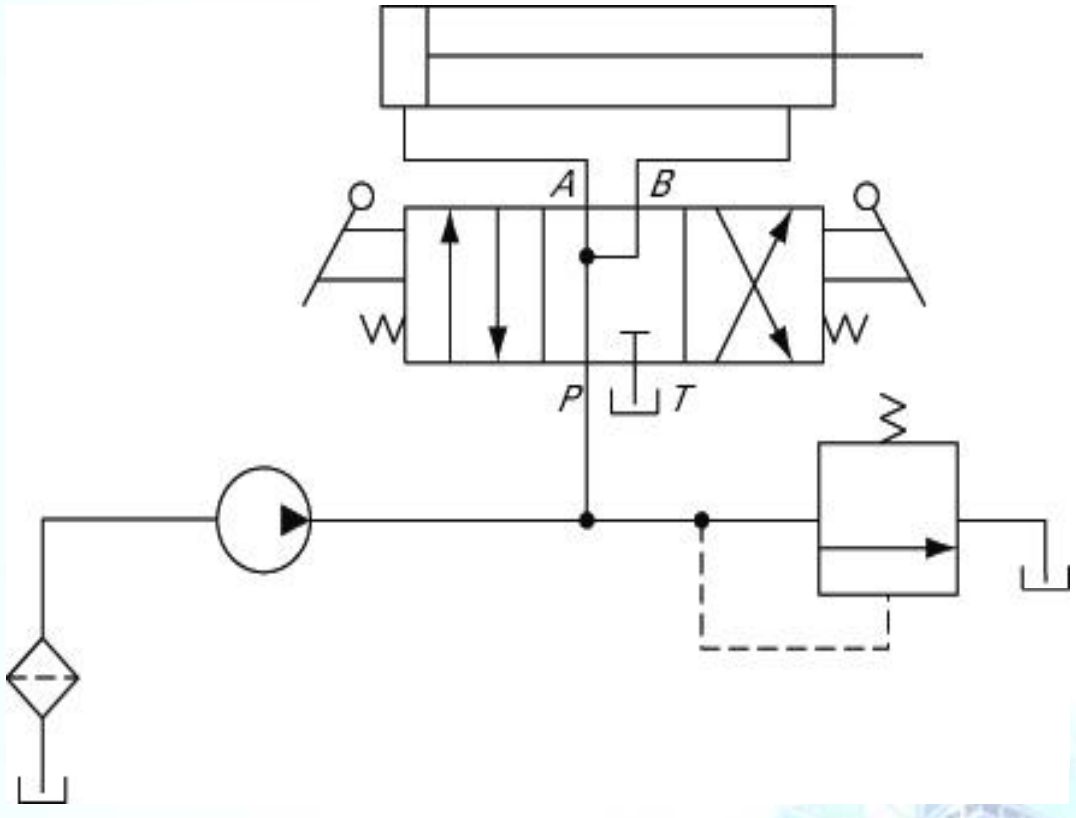
$$v_{P_{ret}} = \frac{Q_P}{A_P - A_r}$$

$$\frac{v_{P_{ext}}}{v_{P_{ret}}} = \frac{Q_P / A_r}{Q_P / (A_P - A_r)}$$
$$= \frac{A_P - A_r}{A_r}$$

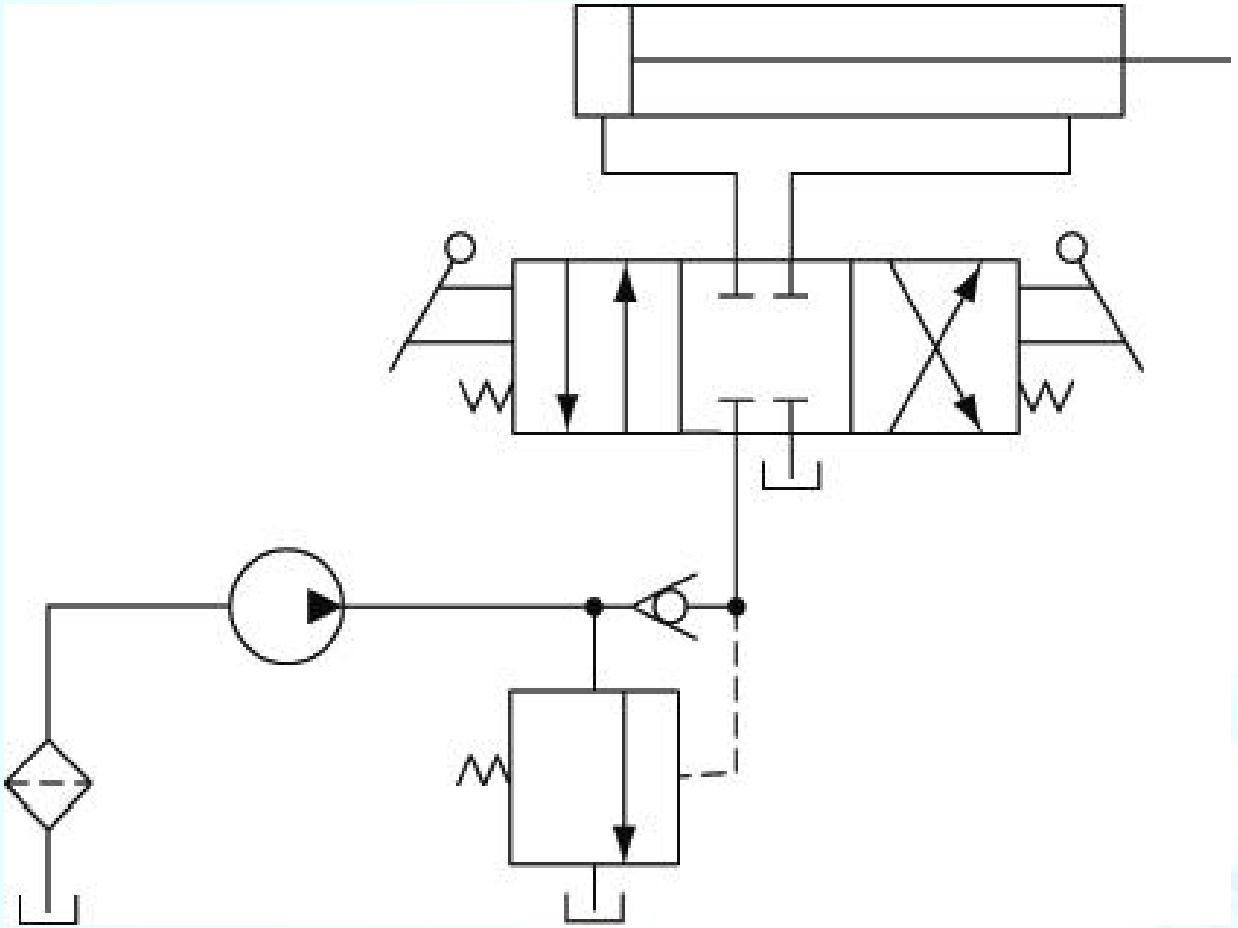
$$\frac{v_{P_{ext}}}{v_{P_{ret}}} = \frac{A_P}{A_r} - 1$$

Drilling Machine Application

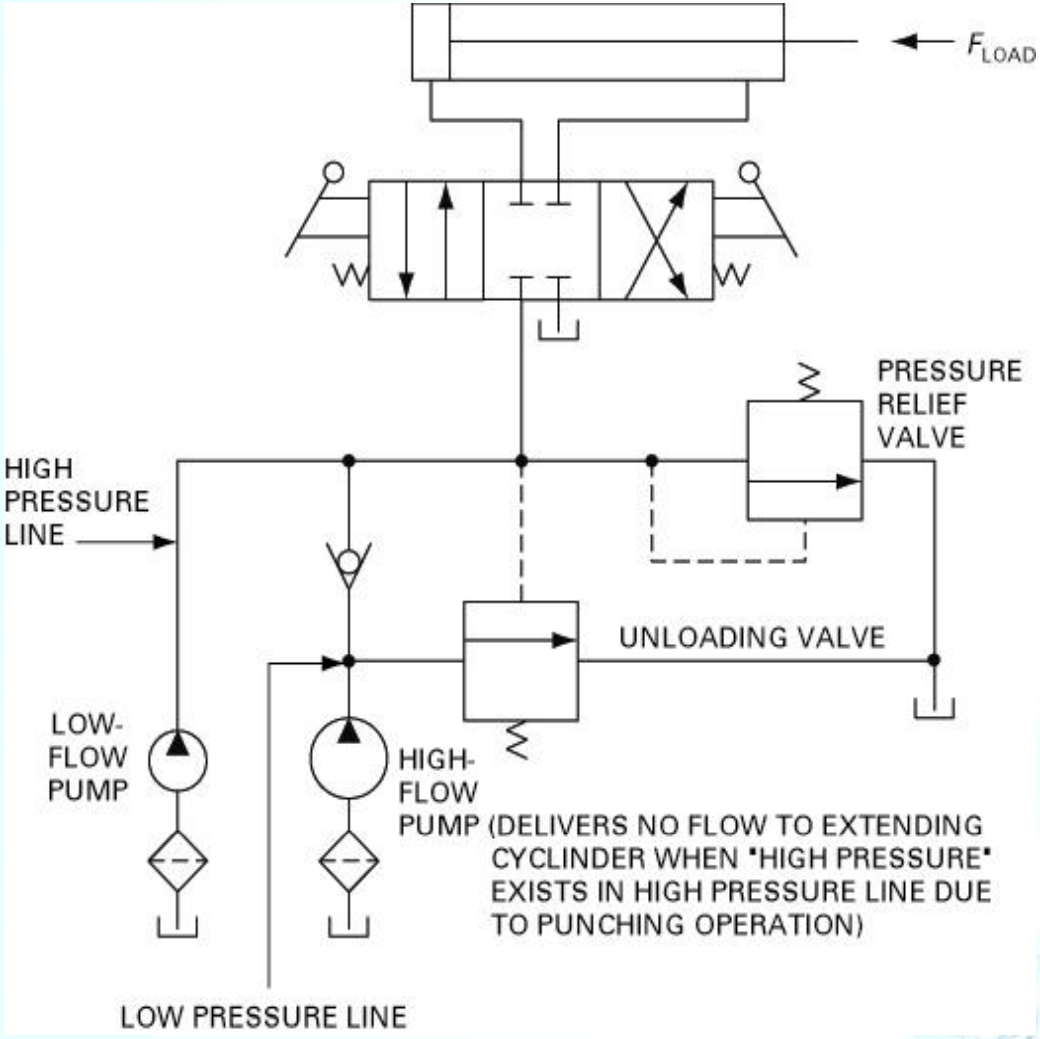
- The spring-centered position gives rapid spindle advance (extension)
- The left envelope mode gives slow feed (extension) when the drill starts to cut into the workpiece
- The right envelope mode retracts the piston



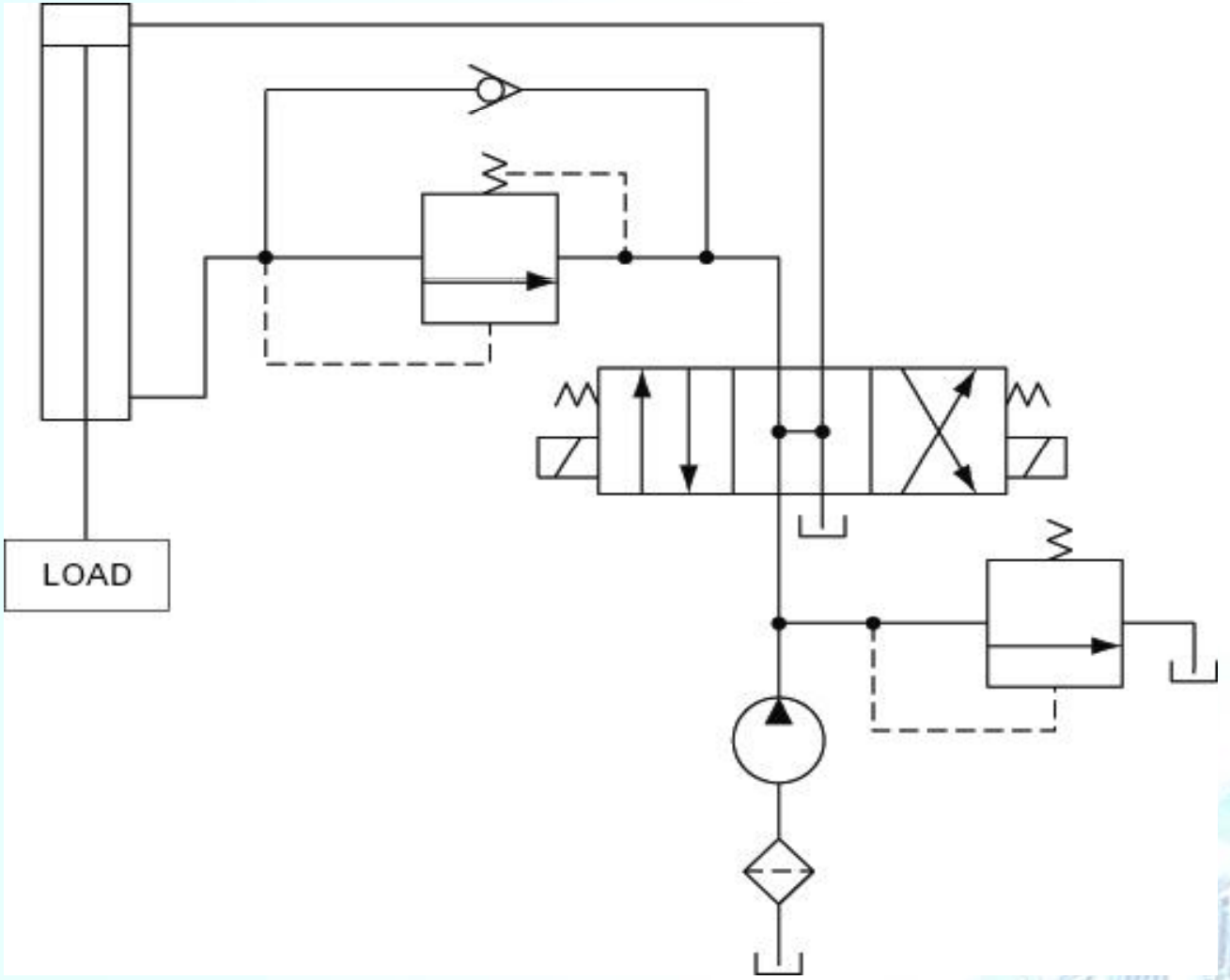
Pump-unloading Circuit



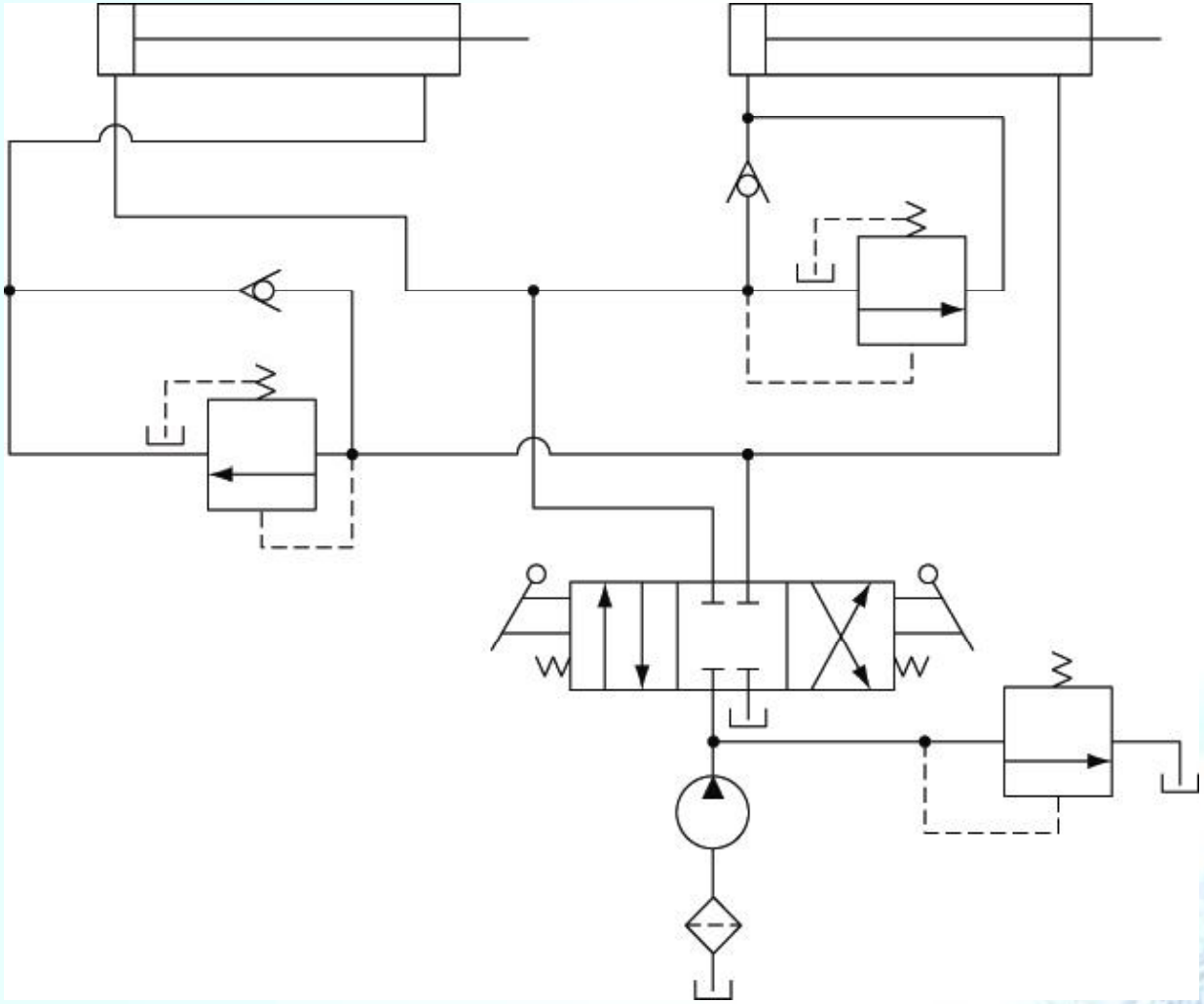
Double-pump Hydraulic System



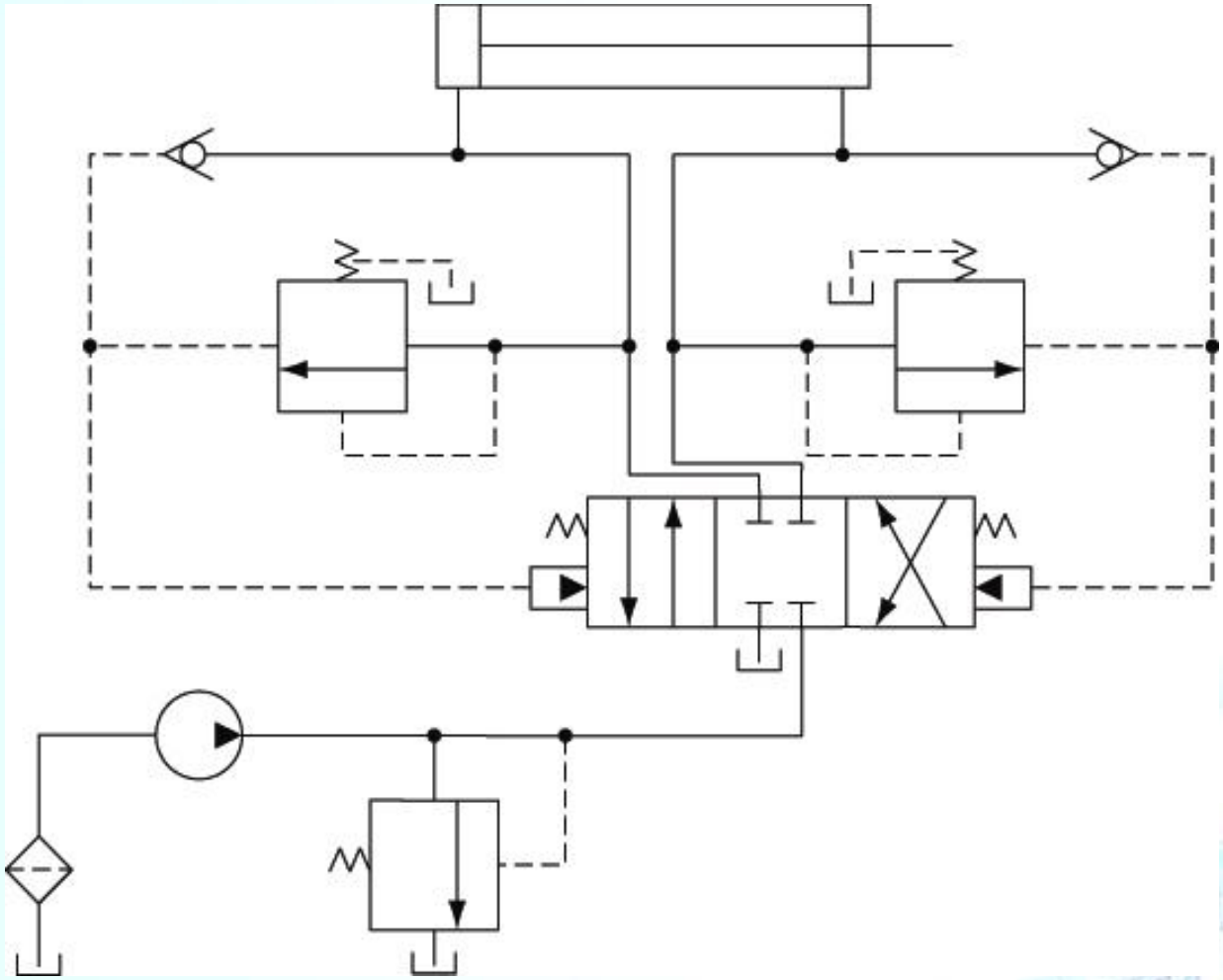
Counterbalance Valve Application



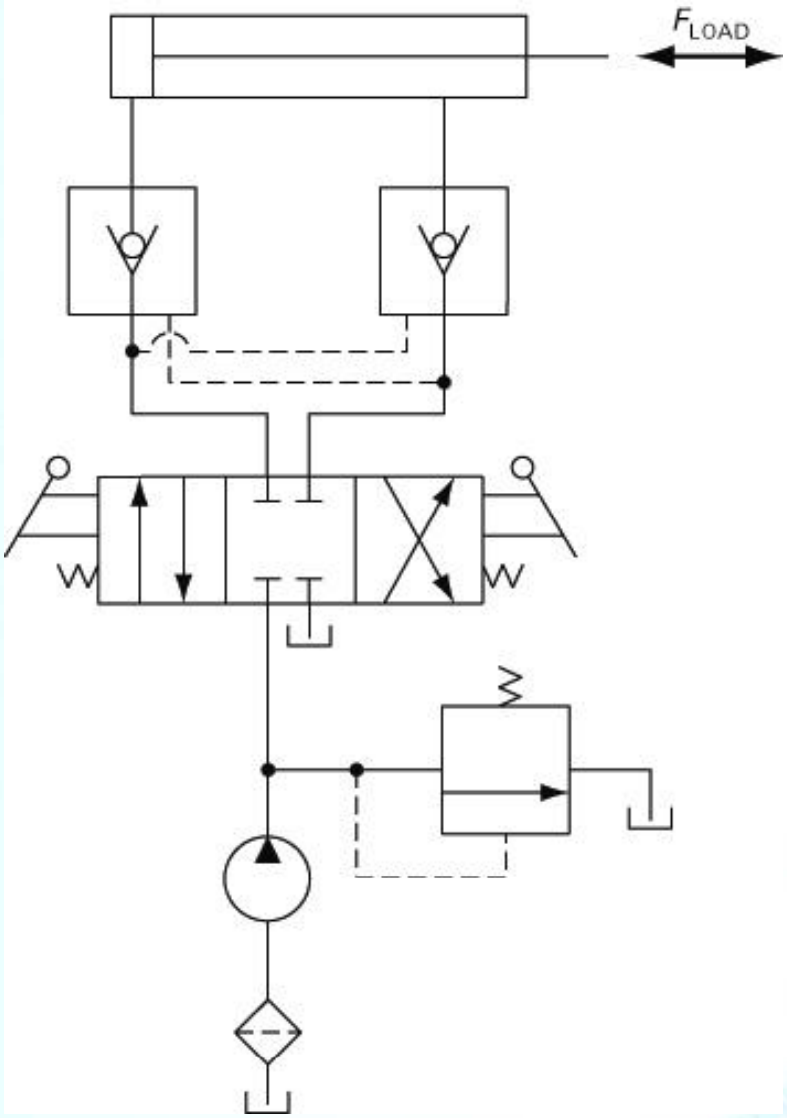
Hydraulic Cylinder Sequence Circuit



Automatic Cylinder Reciprocating System

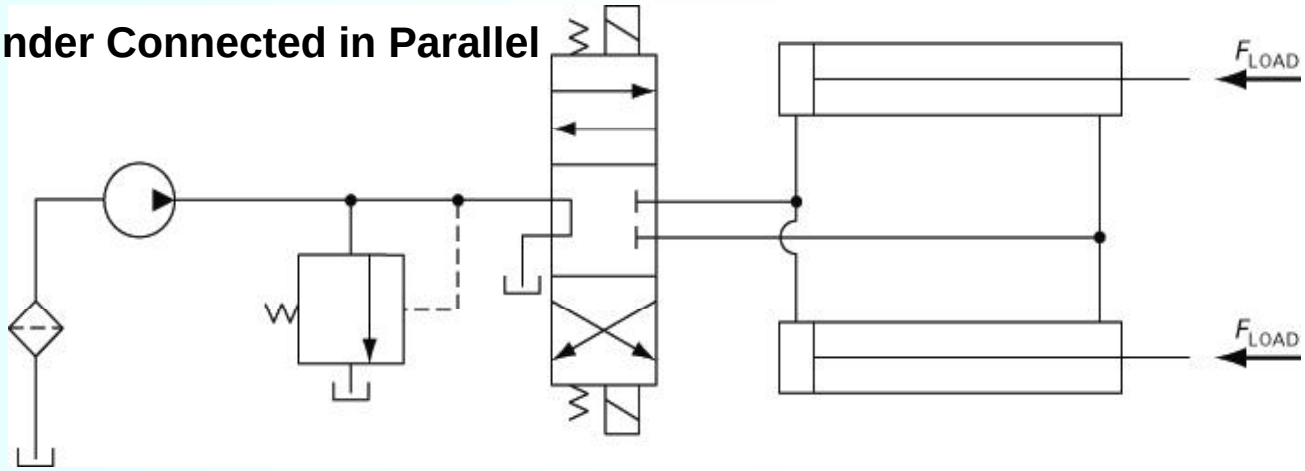


Locked Cylinder using Pilot Check Valves

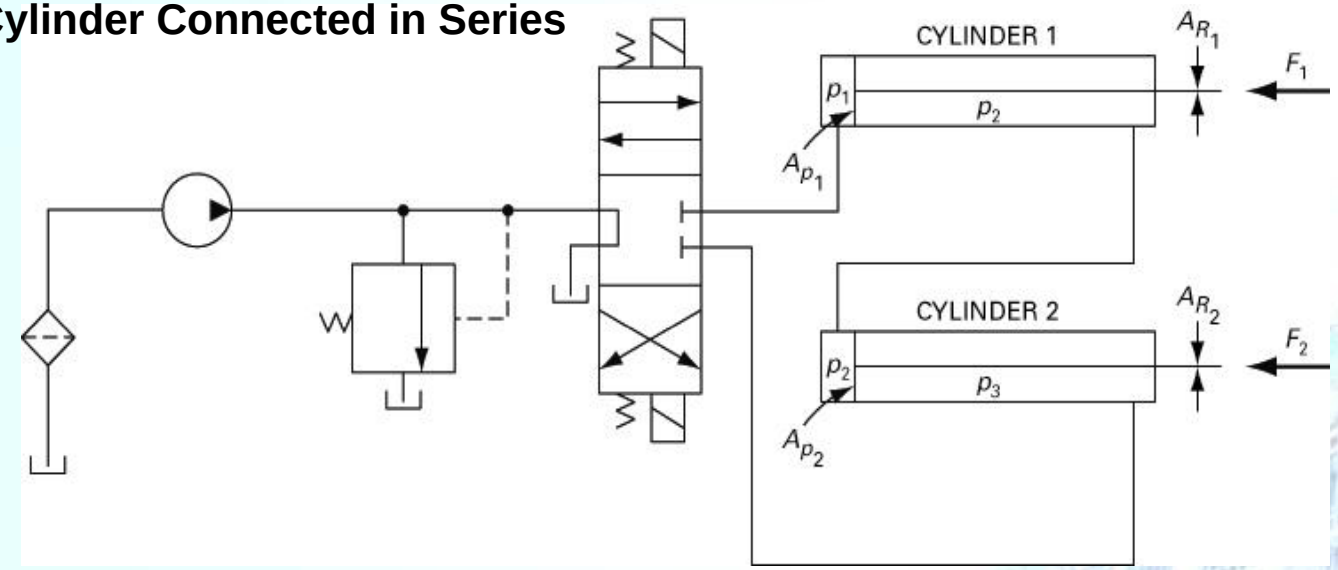


Cylinder Synchronizing Circuits

❖ **Cylinder Connected in Parallel**



❖ **Cylinder Connected in Series**



Analysis of Cylinders hooked in Series

- **continuity equation**

$$Q_{out(cyl1)} = Q_{in(cyl2)}$$

$$(A_{eff}\, v)_{cyl1} = (A_{eff}\, v)_{cyl2}$$

$$(A_{P_1} - A_{R_1})v_1 = A_{P_2} v_2$$

- **for synchronization ($v_1 = v_2$)**

$$A_{P_1} - A_{R_1} = A_{P_2}$$

- **summing force on cylinder 1**

$$p_1 A_{P_1} - p_2 (A_{P_1} - A_{R_1}) = F_1$$

- **summing force on cylinder 2**

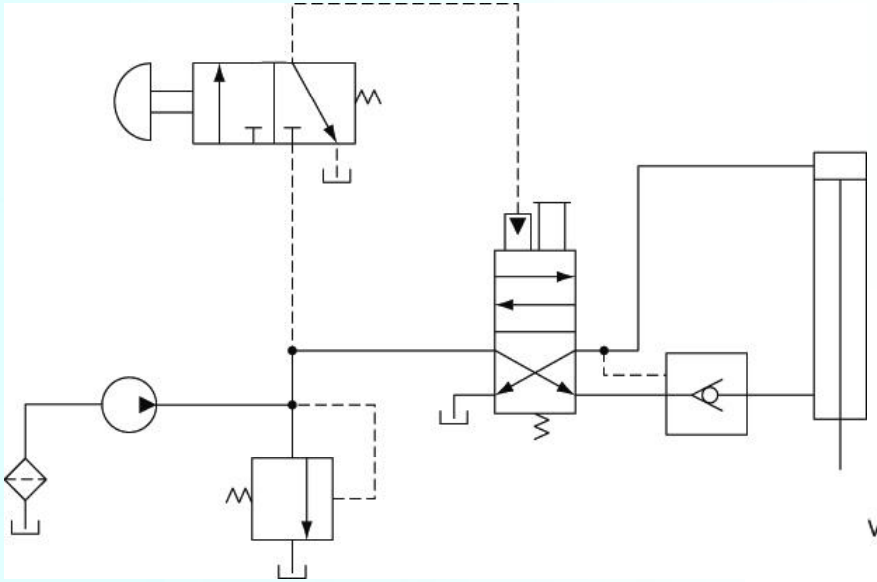
$$p_2 A_{P_2} - p_3 (A_{P_2} - A_{R_2}) = F_2$$

- **desired result**

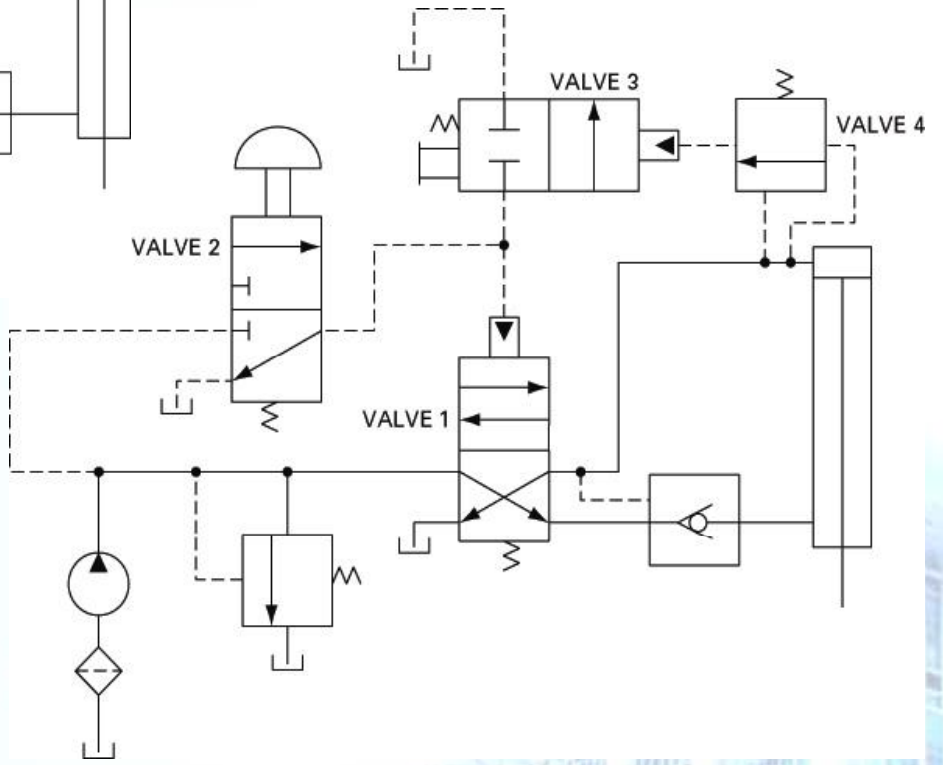
$$p_1 A_{P_1} = F_1 + F_2$$

Fail-Safe Circuits

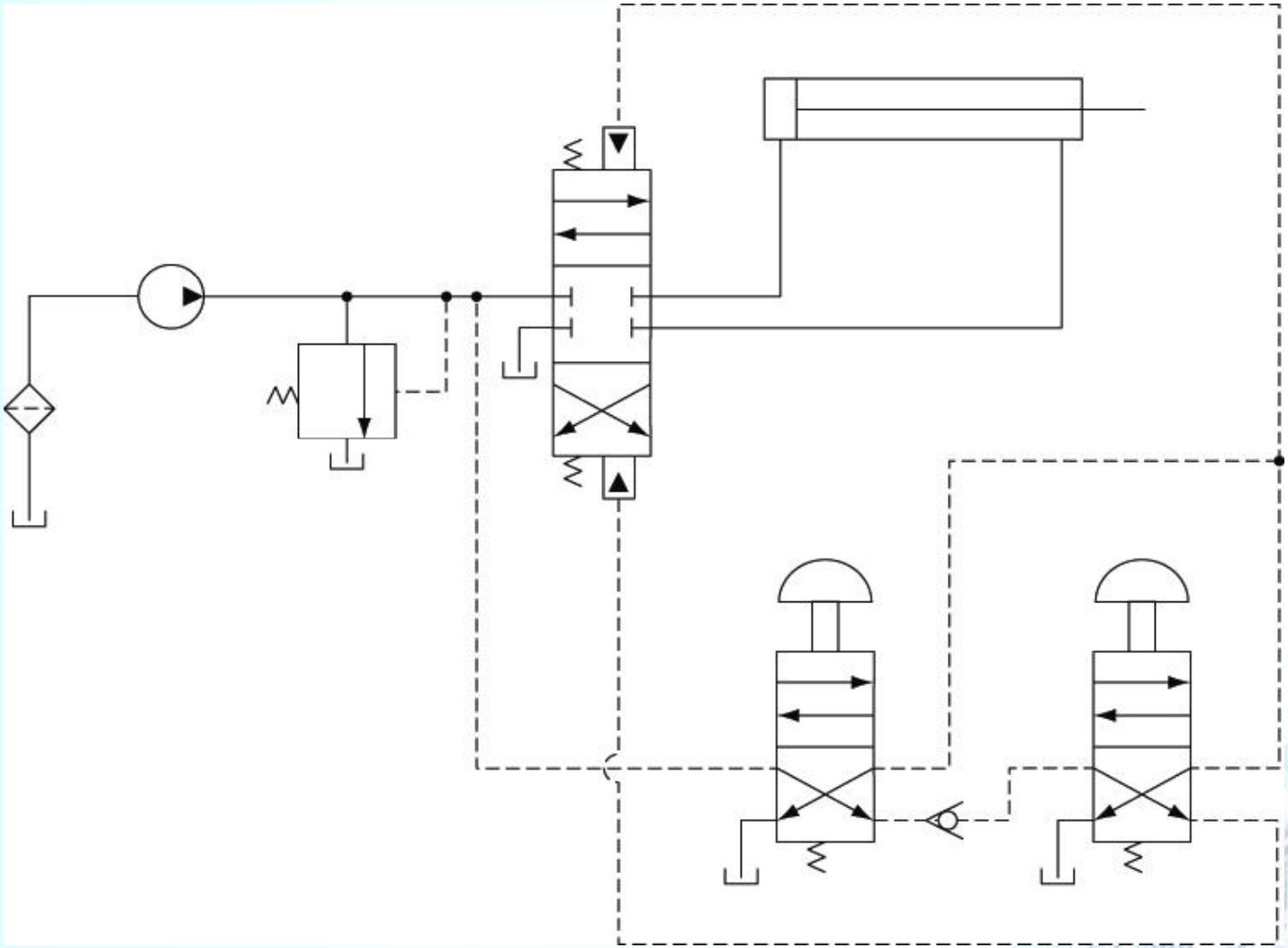
❖ **Fail-safe circuit**



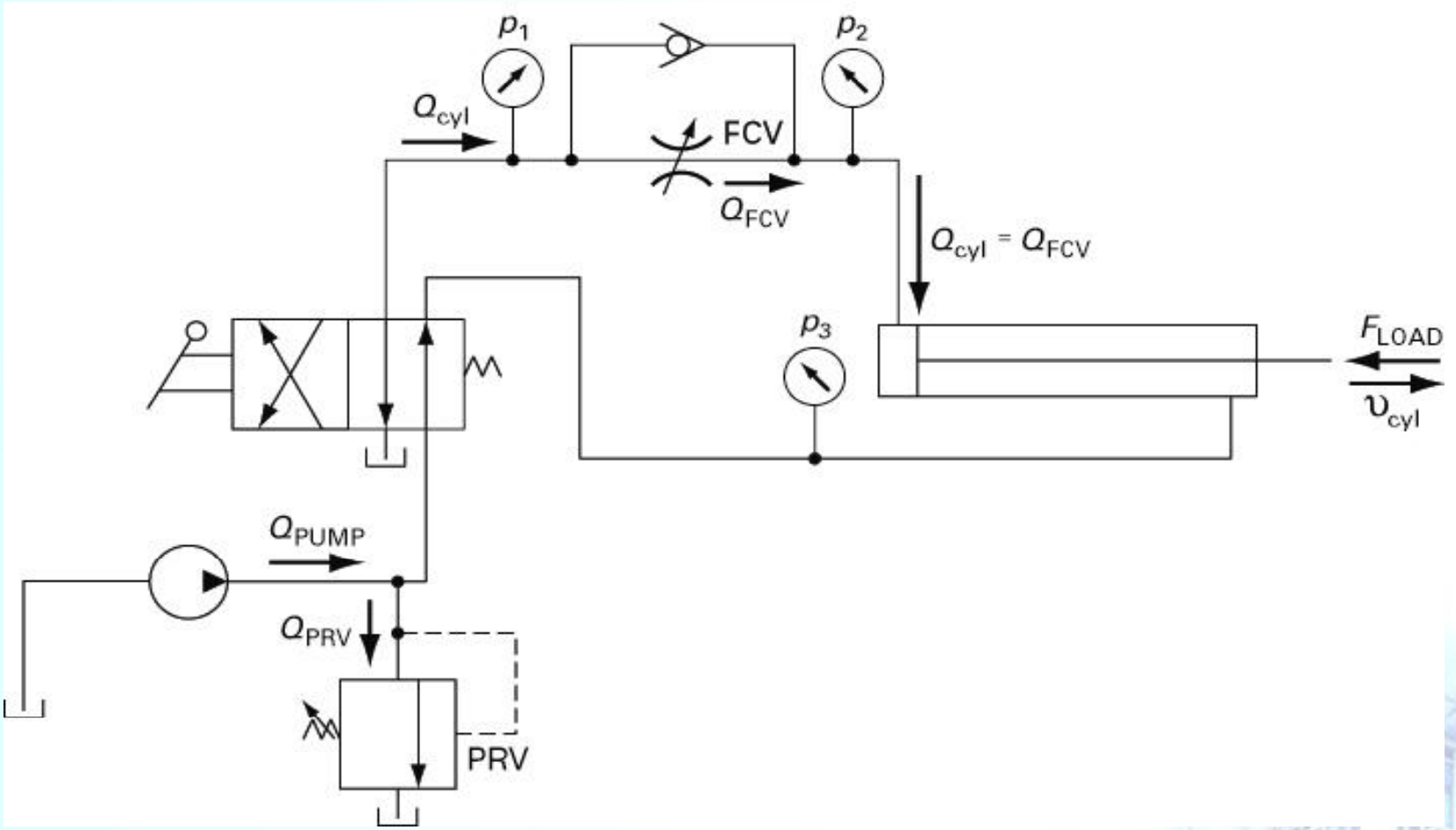
❖ **Fail-safe circuit with overload protection**



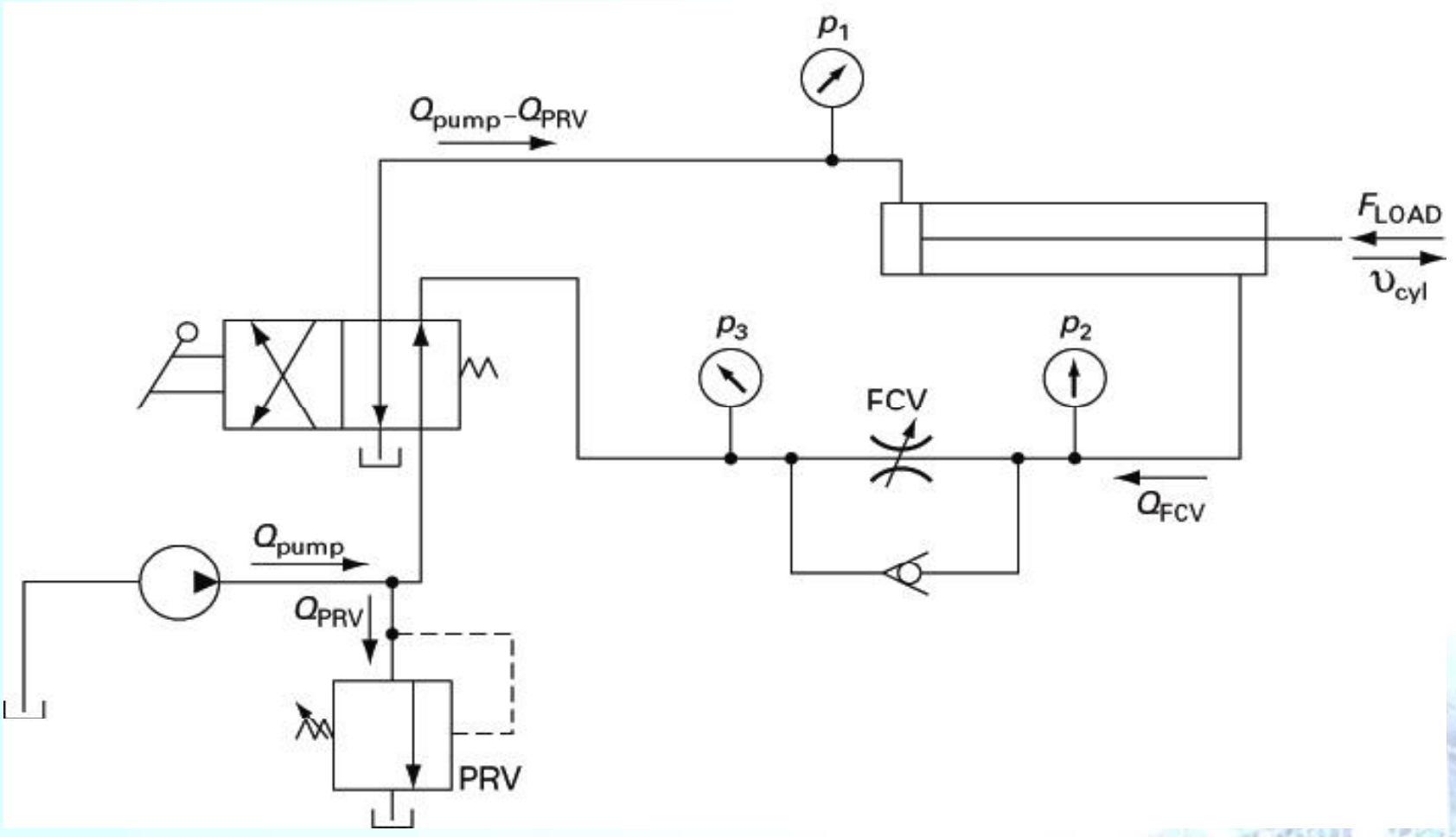
Two-Handed Safety Circuit



Meter-in Speed Control of Hydraulic Cylinder



Meter-out Speed Control of Hydraulic Cylinder



Analysis of Extending Speed Control

- **flow-rate to the cylinder**

$$Q_{cyl} = Q_{pump} - Q_{PRV}$$

- **flow-rate through the flow control valve (FCV)**

$$Q_{FCV} = C_v \sqrt{\frac{\Delta p}{SG}} = C_v \sqrt{\frac{p_1 - p_2}{SG}}$$

- **pressure p_2**

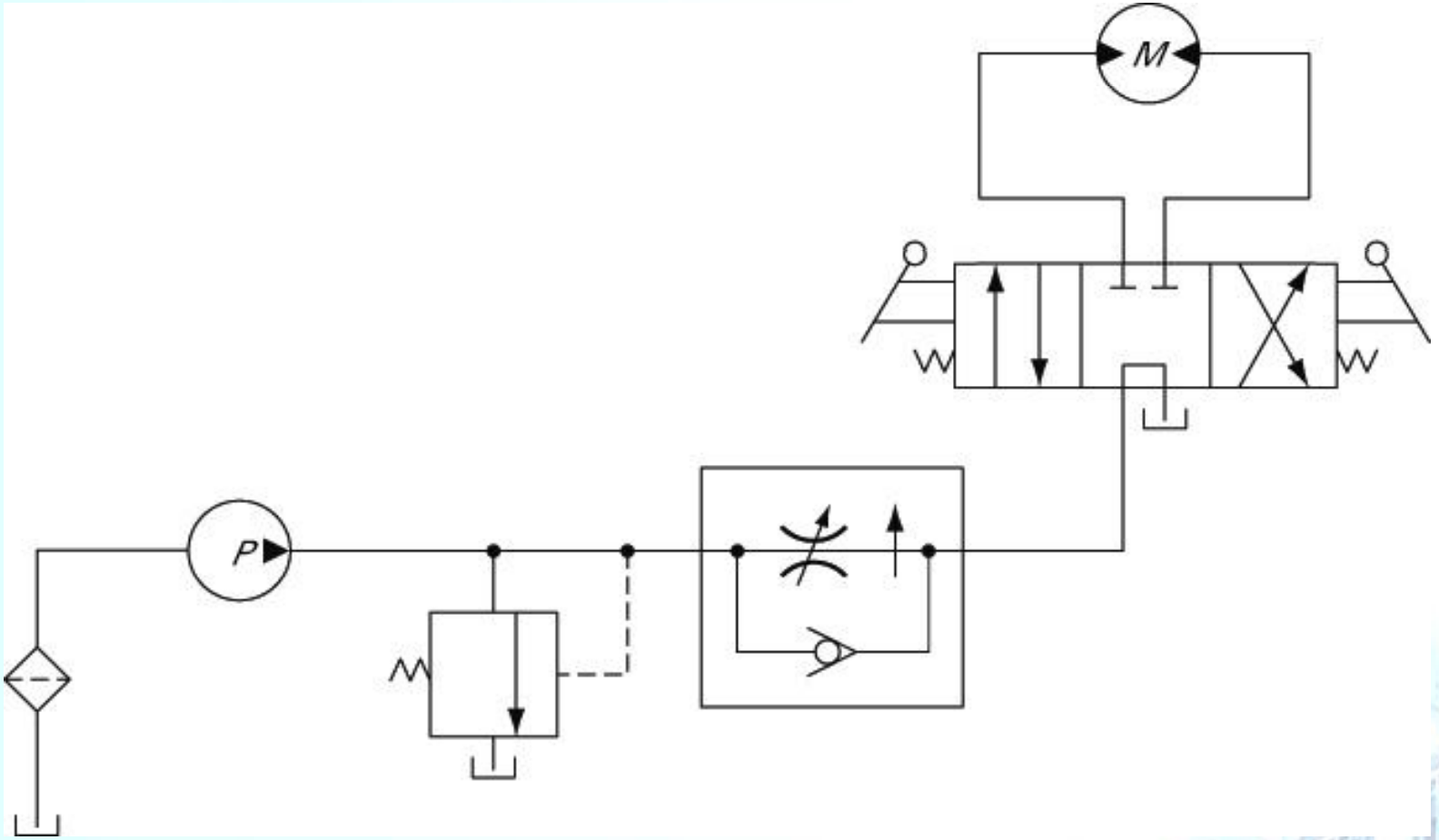
$$p_2 A_{piston} = F_{load} \qquad p_2 = F_{load} / A_{piston}$$

- **extending speed of the cylinder**

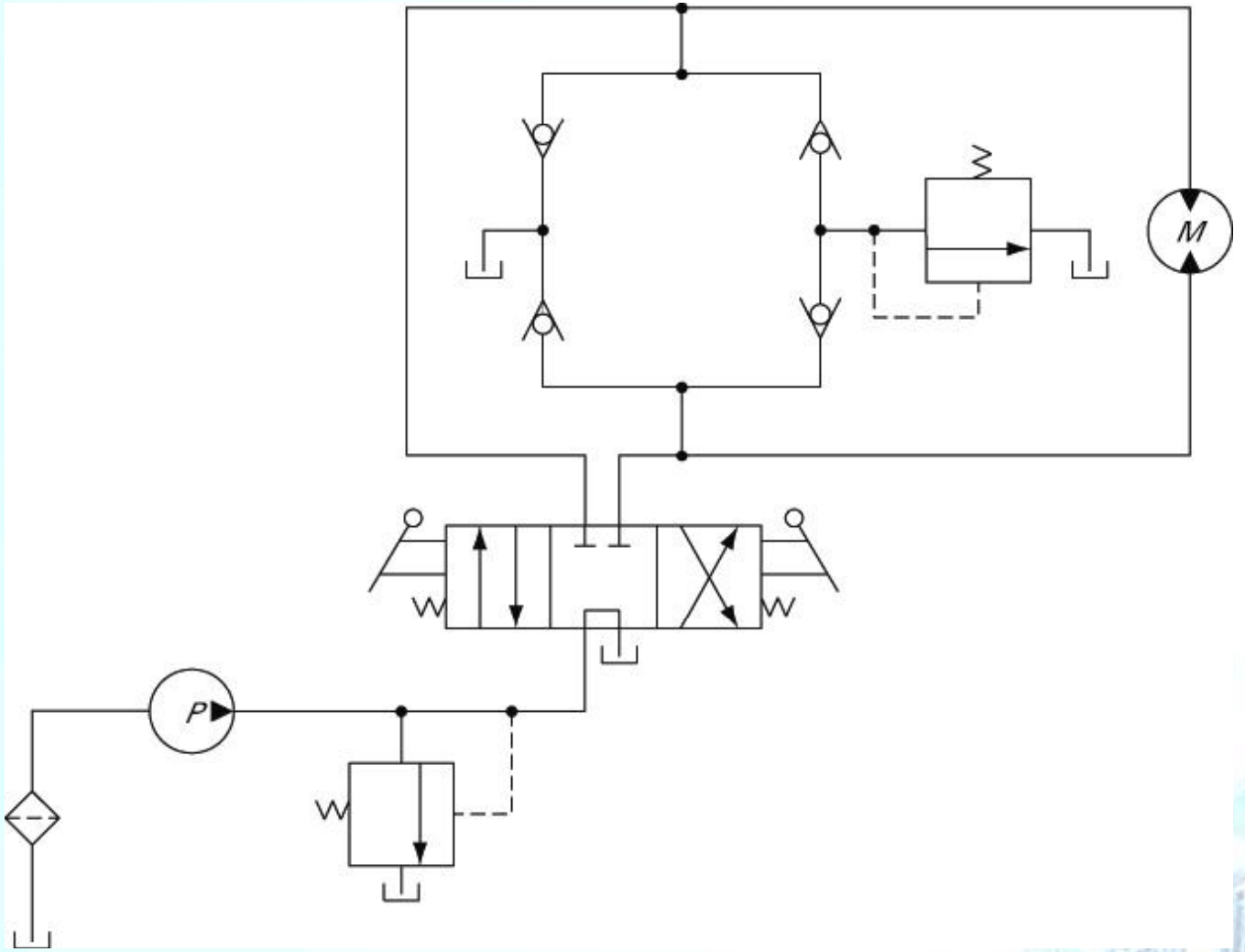
$$v_{cyl} = Q_{cyl} / A_{piston} = Q_{FCV} / A_{piston}$$

$$v_{cyl} = \frac{C_v}{A_{piston}} \sqrt{\frac{p_{PRV} - F_{load} / A_{piston}}{SG}}$$

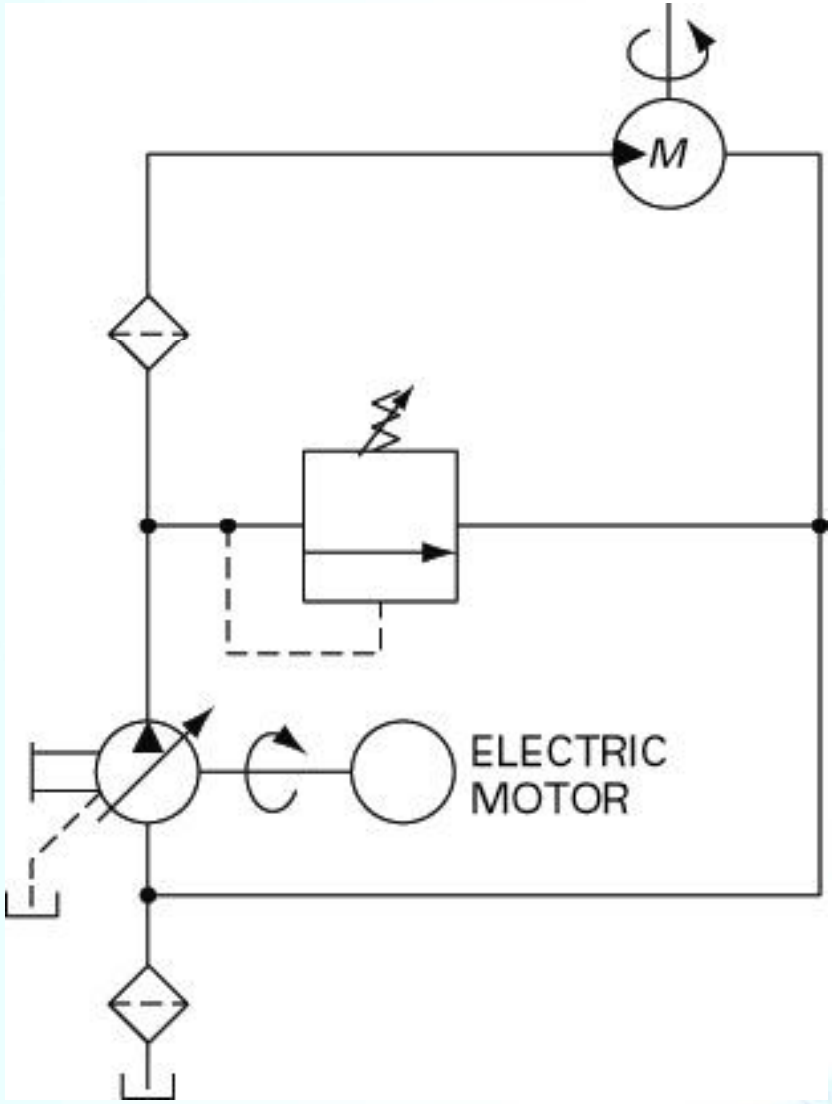
Speed Control of Hydraulic Motor



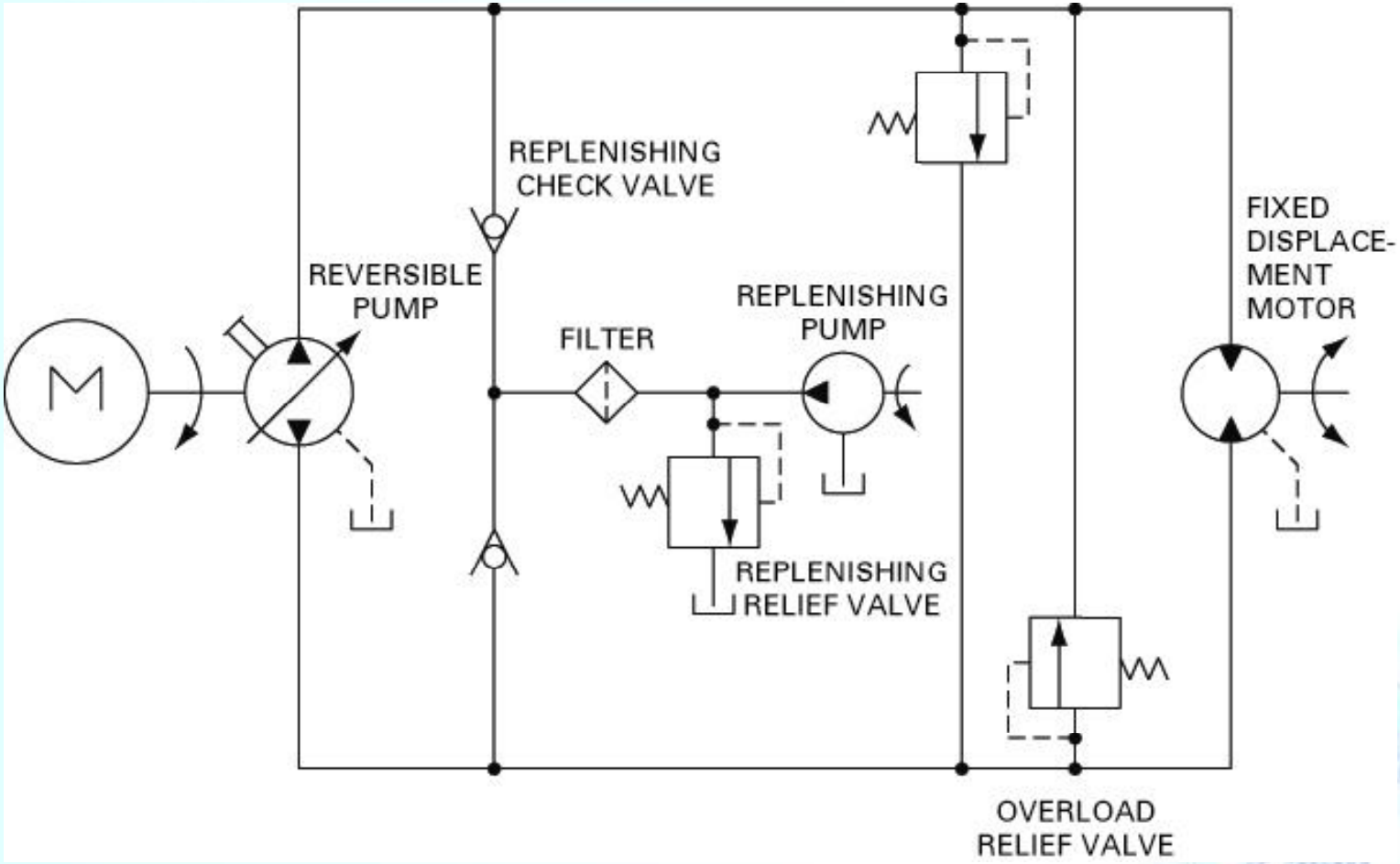
Hydraulic Motor Braking System



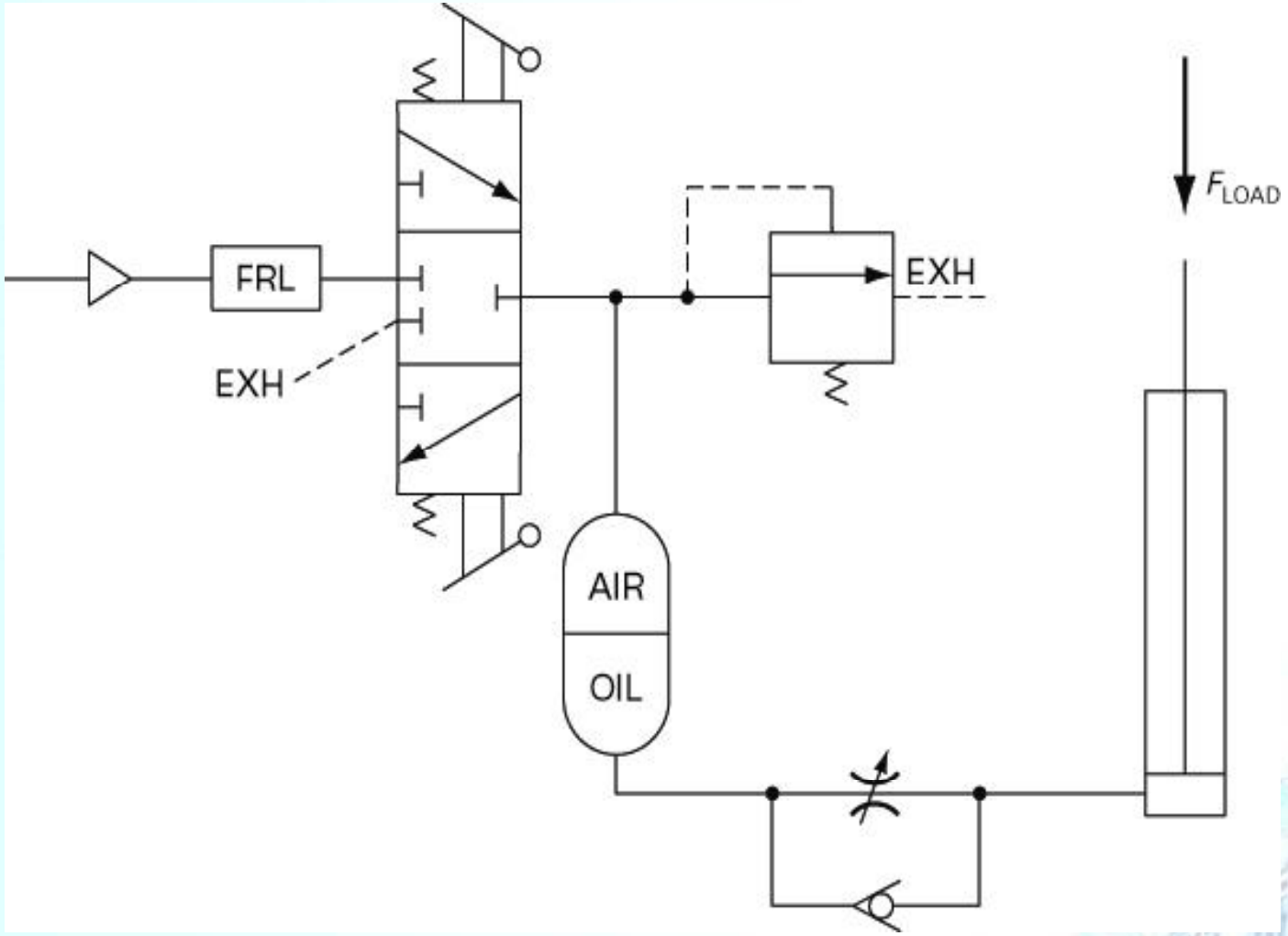
Closed-circuit One-direction HST



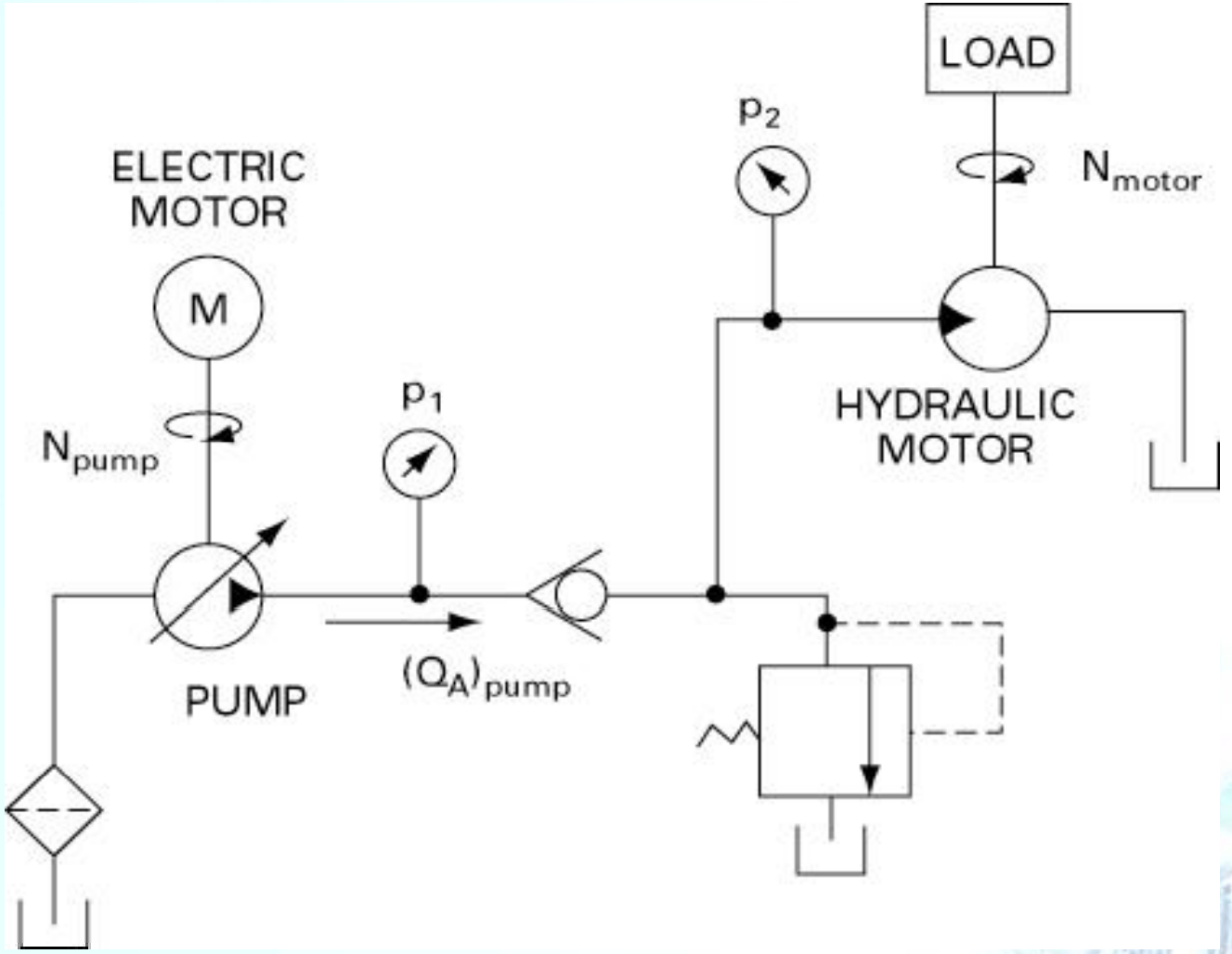
Closed-circuit Reversible-direction HST



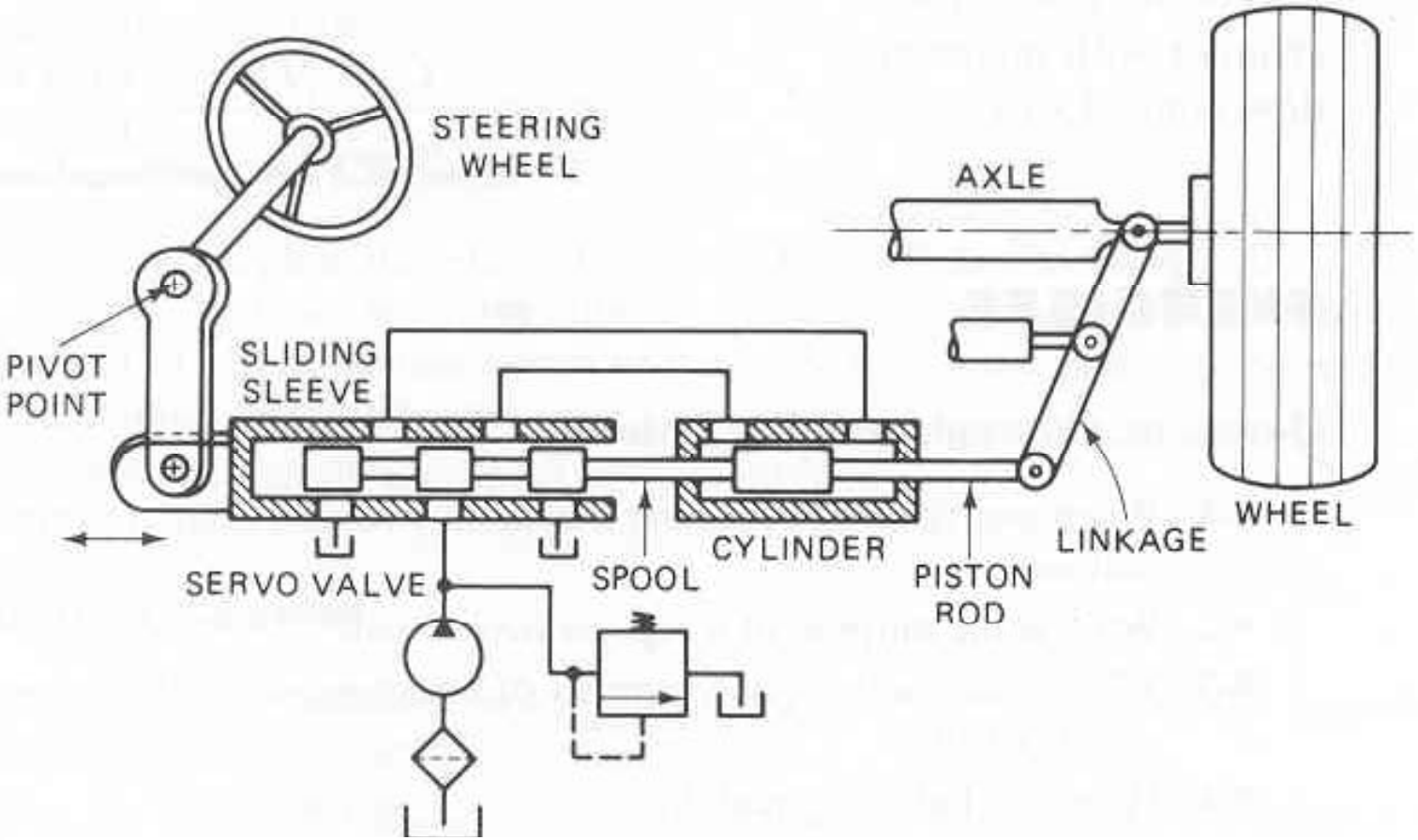
Air-over-oil Circuit



Example: Analysis of Hydraulic System



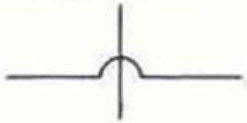
Mechanical-hydraulic Servo System

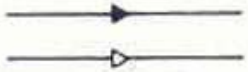
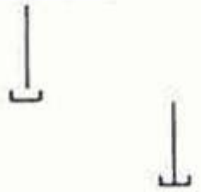
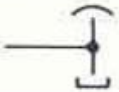


9.A Fluid Power Symbols

- Line & Line Functions
- Pumps
- Motors
- Cylinders
- Miscellaneous Units
- Basic Valve Symbols
- Valve Examples
- Methods of Operation

Lines & Line Functions

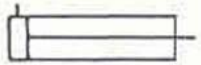
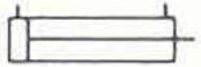
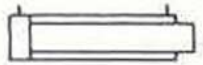
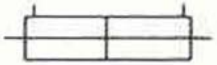
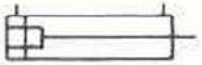
LINE, WORKING	
LINE, PILOT (L>20W)	
LINE, DRAIN (L<5W)	
CONNECTOR	
LINE, FLEXIBLE	
LINE, JOINING	
LINE, PASSING	

DIRECTION OF FLOW, HYDRAULIC PNEUMATIC	
LINE TO RESERVOIR ABOVE FLUID LEVEL BELOW FLUID LEVEL	
LINE TO VENTED MANIFOLD	
PLUG OR PLUGGED CONNECTION	
RESTRICTION, FIXED	

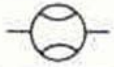
Pumps, Motors & Cylinders

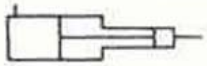
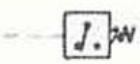
PUMP, SINGLE FIXED DISPLACEMENT	
PUMP, SINGLE VARIABLE DISPLACEMENT	

MOTOR, ROTARY FIXED DISPLACEMENT	
MOTOR, ROTARY VARIABLE DISPLACEMENT	
MOTOR, OSCILLATING	

CYLINDER, SINGLE-ACTING	
CYLINDER, DOUBLE-ACTING	
CYLINDER, DIFFERENTIAL ROD	
CYLINDER, DOUBLE-END ROD	
CYLINDER, CUSHIONS BOTH ENDS	

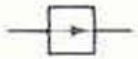
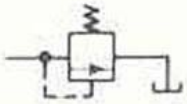
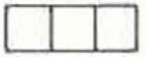
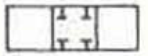
Miscellaneous Units

DIRECTION OF ROTATION (ARROW IN FRONT OF SHAFT)	
COMPONENT ENCLOSURE	
RESERVOIR, VENTED	
RESERVOIR, PRESSURIZED	
PRESSURE GAGE	
TEMPERATURE GAGE	
FLOW METER (FLOW RATE)	
ELECTRIC MOTOR	

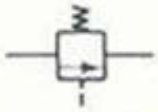
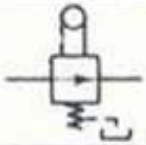
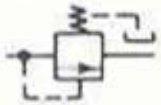
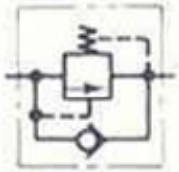
ACCUMULATOR, SPRING-LOADED	
ACCUMULATOR, GAS-CHARGED	
FILTER OR STRAINER	
HEATER	
COOLER	
TEMPERATURE CONTROLLER	
INTENSIFIER	
PRESSURE SWITCH	

Basic Valve Symbols

CHECK VALVE	
MANUAL SHUT-OFF VALVE	
BASIC VALVE ENVELOPE	
VALVE, SINGLE-FLOW PATH, NORMALLY CLOSED	

VALVE, SINGLE-FLOW PATH, NORMALLY OPEN	
VALVE, MAXIMUM PRESSURE (RELIEF)	
BASIC VALVE SYMBOL, MULTIPLE FLOW PATHS	
FLOW PATHS BLOCKED IN CENTER POSITION	
MULTIPLE FLOW PATHS (ARROW SHOWS FLOW DIRECTION)	

Valve Examples

UNLOADING VALVE, INTERNAL DRAIN, REMOTELY OPERATED	
DECELERATION VALVE, NORMALLY OPEN	
SEQUENCE VALVE, DIRECTLY OPERATED, EXTERNALLY DRAINED	
PRESSURE-REDUCING VALVE	
COUNTERBALANCE VALVE WITH INTEGRAL CHECK	

TEMPERATURE- AND PRESSURE-COMPENSATED FLOW CONTROL WITH INTEGRAL CHECK	
DIRECTIONAL VALVE, TWO-POSITION, THREE-CONNECTION	
DIRECTIONAL VALVE, THREE-POSITION, FOUR-CONNECTION	
PROPORTIONAL DIRECTIONAL CONTROL VALVE, INFINITE POSITIONING (INDICATED BY HORIZONTAL BARS)	

Methods of Operation

PRESSURE COMPENSATOR	
DETENT	
MANUAL	
MECHANICAL	
PEDAL OR TREADLE	
PUSH BUTTON	
LEVER	

PILOT PRESSURE	
SOLENOID	
SOLENOID-CONTROLLED, PILOT-PRESSURE-OPERATED	
SPRING	
SERVO	

한국공업규격

- 유압용어: **KS B 0119**
- 유압.공기압 도면 기호: **KS B 0054**
- **Report #9**
  - **KS** 유공압관련 규격 찾아 볼 것

Report

- **Text Problems**
  - **9-16**
  - **9-28**
  - **9-45**
- **Due date: 2주후**