MODULE – 3 Hydraulic Circuit Design and Maintenance

Circuit design: Control of single acting and double acting hydraulic cylinder, regenerative circuit, pump unloading circuit, double pump hydraulic system, hydraulic cylinder sequencing
circuits, maintenance of hydraulic system

HYDRAULIC CIRCUIT DESIGN

- A hydraulic circuit is a group of components such as pumps, actuators, control valves, and conductors arranged so that they will perform a useful task.
- Hydraulic circuits are developed using graphic symbols for all components.

There are three important considerations in designing a hydraulic circuit:

1) Safety of machine and personnel in the event of power failures.
2) Performance of given operation with minimum losses.
3) Cost of the component used in the circuit.

DESIGN CONSIDERATIONS

1) Safety of Operation

- Pressure and Temperature ratings
- Interlocks for sequential operations
- Emergency shutdown features
- Power failure locks
- Operation speed
- Environment conditions

2) Meet functional requirements

- Life expectancy same as machine
- Facilitate good maintenance practice
- Compatibility with electrical and mechanical components
- Withstand operational hazards

3) Efficiency of Operation

- Keep system Simple, Safe and Functional
- Access to parts need repair or adjustment
- Design to keep minimum operational cost
- Design to prevent and remove contamination.

CONTROL OF A SINGLE ACTING HYDRAULIC CYLINDER

The Control of a Single Acting Hydraulic Cylinder shown in figure below, the components

- Single-acting, spring return cylinder ,
- **P-** Pump; **M** = Electric Motor ; **T** = Tank; Filter
- Flow Control Valve with Check Valve Combination ; Pressure Relief Valve
- 3-way 2-position, DCV Manually operated and spring Return (3/2 DCV)
- Figure shows that the control of a single-acting, spring return cylinder using a three-way two-position manually actuated, spring offset direction-control valve (DCV).
- In the spring offset mode, full pump flow goes to the tank via the pressure relief valve.
- The spring in the rod end of the cylinder retracts the piston **as oil from the blank end 'A' drains back to the tank.**
- When the valve is manually actuated, **the pump flow goes to the cylinder blank end 'A'** via DCV -1 position. This extends the cylinder. At full extension, pump flow goes through the relief valve.
- Deactivation of the DCV allows the cylinder to retract as the DCV shift into its spring – offset mode.

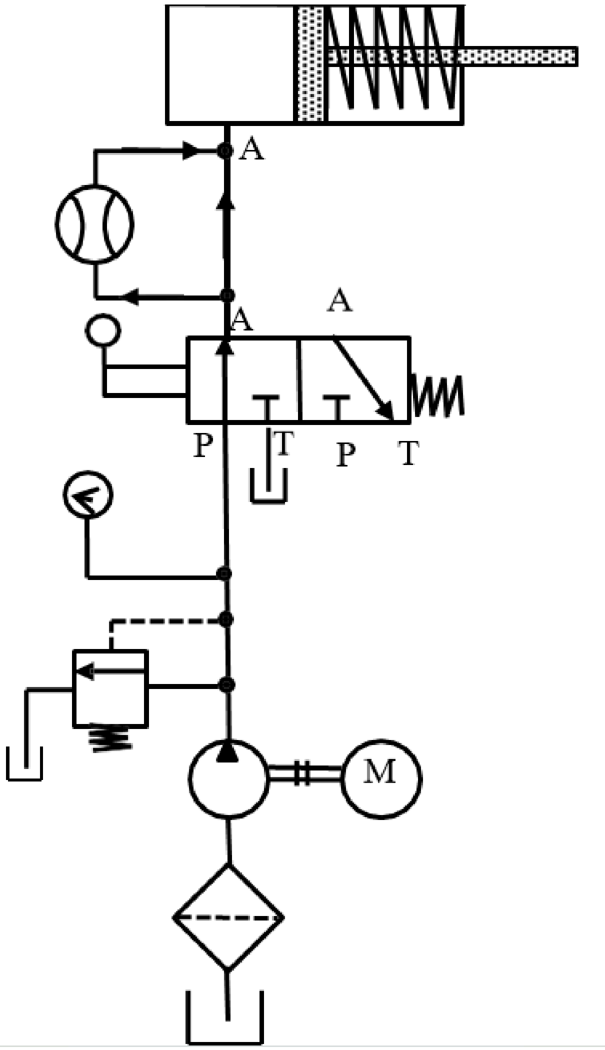

Fig. Control of a Single Acting Hydraulic Cylinder

CONTROL OF A DOUBLE ACTING HYDRAULIC CYLINDER

The circuit diagram to control double-acting cylinder is shown in Fig.

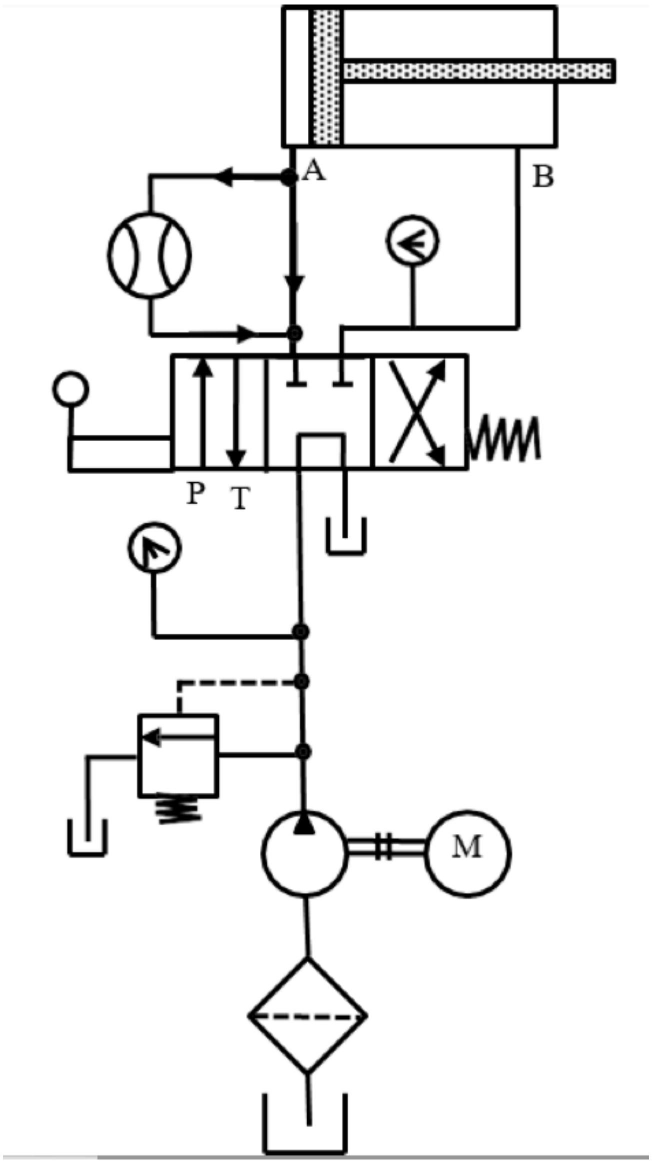

Fig. Control of a Double Acting Hydraulic Cylinder

The control of a double-acting hydraulic cylinder is described as follows:

1) When the 4/3 valve is in its neutral position (tandem design), **the cylinder is hydraulically locked** and the pump is unloaded back to the tank.
2) When the 4/3 valve is actuated into the flow path, the cylinder is extended against its load as oil flows **from port -P through port - A**. Oil in the rod end of the cylinder is free to flow back to the tank through the four-way valve from **port -B through port -T.**
3) When the 4/3 valve is actuated into the right-envelope configuration, the cylinder retracts as oil flows from **port-P through port-B**. Oil in the blank end is returned to the tank via the flow path from port A to port T.

- At the ends of the stroke, there is no system demand for oil. Thus, the pump flow goes through the relief valve at its pressure level setting unless the four-way valve is deactivated.

REGENERATIVE CIRCUIT

- Figure shows a regenerative circuit that is **used to speed up the extending speed** of a double-acting cylinder.

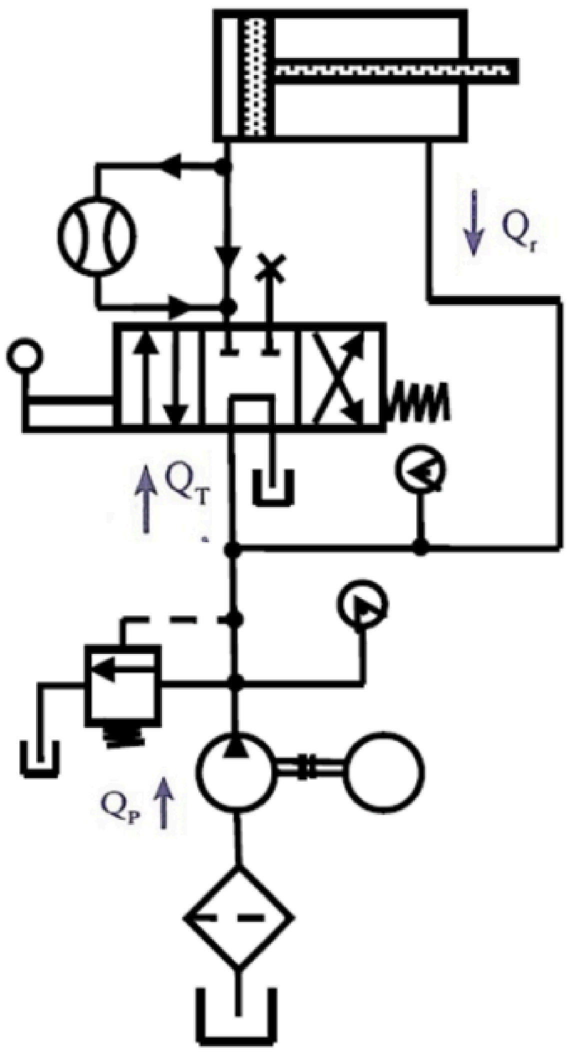

Fig. Regenerative circuit that is used to speed up the extending speed

- The pipelines to both ends of the hydraulic cylinder are connected in parallel and **one of the ports of the 4/3 valve is blocked by simply screwing a thread plug into the port opening**.
- During retraction stroke, **the 4/3 valve is configured to the right envelope.** During this stroke, the pump flow bypasses the DCV and enters the rod end of the cylinder. Oil from the blank end then drains back to the tank through the DCV.
- When the DCV is shifted in to its left-envelope configuration, the cylinder extends as shown in Fig.

- The speed of extension is greater than that for a regular double-acting cylinder because the flow from the rod end regenerates with the **pump flow Q_P** to provide a **total flow rate Q_T**.

PUMP-UNLOADING CIRCUIT

Figure shows a hydraulic circuit to unload a pump using an unloading valve.

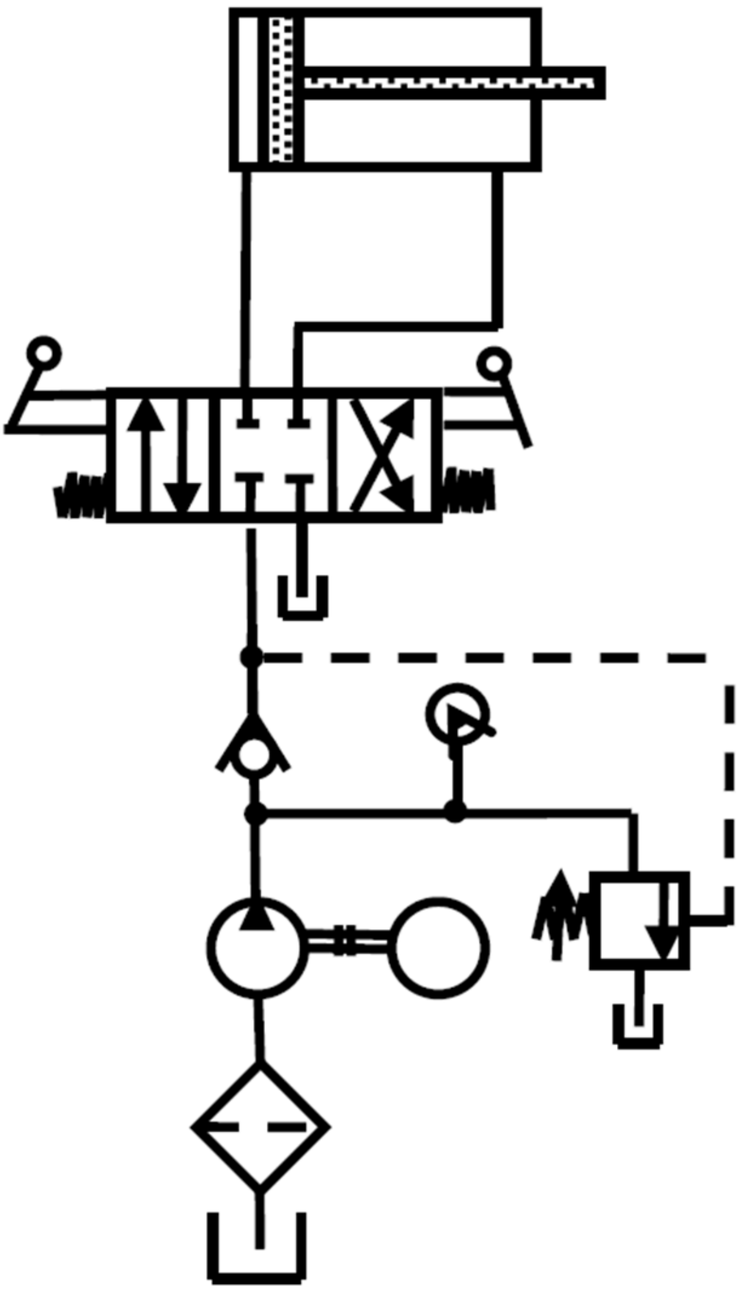

Fig. Hydraulic circuit to unload a pump using an unloading valve

- When the cylinder reaches the end of its extension stroke, the pressure of oil rises because the **check valve keeps the high- pressure oil**. Due to high-pressure oil in the **pilot line of the unloading valve**, it opens and unloads the pump pressure to the tank.

- When the DCV is shifted to retract the cylinder, the motion of the piston reduces the pressure in the pilot line of the unloading valve. **This resets the unloading valve until the cylinder is fully retracted.**
- When this happens, the unloading valve unloads the pump due to high-pressure oil. Thus, the unloading valve unloads the pump at the ends of the extending and retraction strokes as well as in the spring-centered position of the DCV.

DOUBLE-PUMP HYDRAULIC SYSTEM

- Figure shows an application for an unloading valve.
- It is a circuit that uses a high-pressure, low-flow pump in conjunction with a **low-pressure, high-flow pump.**
- A typical application is a sheet metal punch press in which the hydraulic cylinder must extend rapidly over a great distance with low-pressure but high-flow requirements.

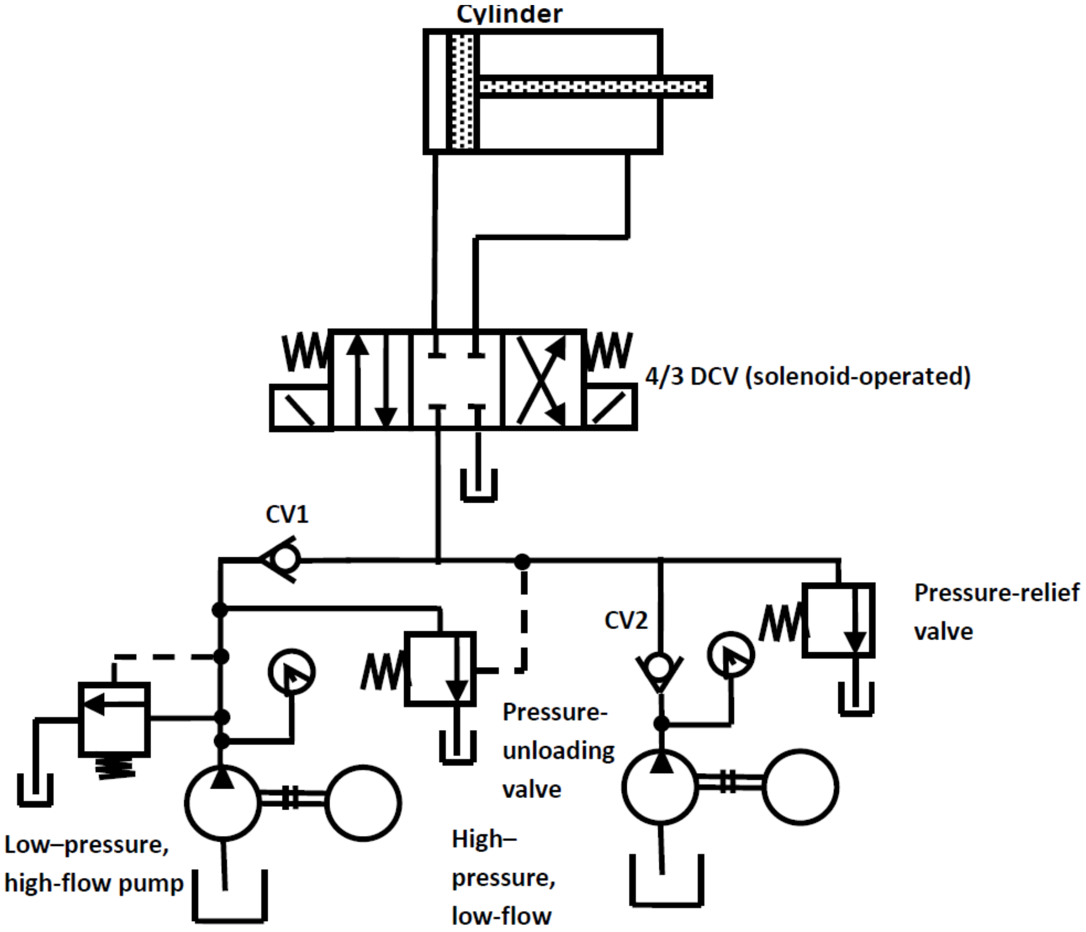

Fig. Double-Pump Hydraulic System (an application for an unloading valve)

Main Components:

- **Cylinder:** Actuator that extends/retracts for pressing operations.
- **4/3 Directional Control Valve (DCV)**: Solenoid-operated valve directs fluid flow to extend/retract the cylinder or hold its position (center).
- **Low-Pressure, High-Flow Pump**: Delivers large flow at low pressure for rapid cylinder movement.

- **High-Pressure, Low-Flow Pump**: Provides high pressure needed for pressing/work portion of the cycle.
- **Check Valves (CV1, CV2)**: Prevent backflow; allow proper flow direction depending on which pump is active.
- **Pressure-Unloading Valve**: Automatically unloads the low-pressure/high-flow pump when system pressure reaches a preset value (e.g., when the cylinder meets resistance at the end of its rapid extension).
- **Pressure Relief Valve**: Protects the system from overpressure.
- When the punching operation begins, the increased pressure opens the unloading valve to unload the low- pressure pump.
- The purpose of relief valve is to protect the high-pressure pump from over pressure at the end of cylinder stroke and **when the DCV is in its spring-centered mode.**
- The check valve protects the low-pressure pump from high pressure, which occurs during punching operation, at the ends of the cylinder stroke and **when the DCV is in its spring-centered mode.**

HYDRAULIC CYLINDER SEQUENCING CIRCUITS

- Hydraulic cylinders can be operated sequentially using a sequence valve. Figure shows that two sequence valves are used to sequence the operation of two double-acting cylinders.
- This hydraulic circuit can be used in a production operation such as drilling.
- The circuit guarantees precise sequencing: Drilling cylinder (B) retracts first, then clamp cylinder (A) retracts.

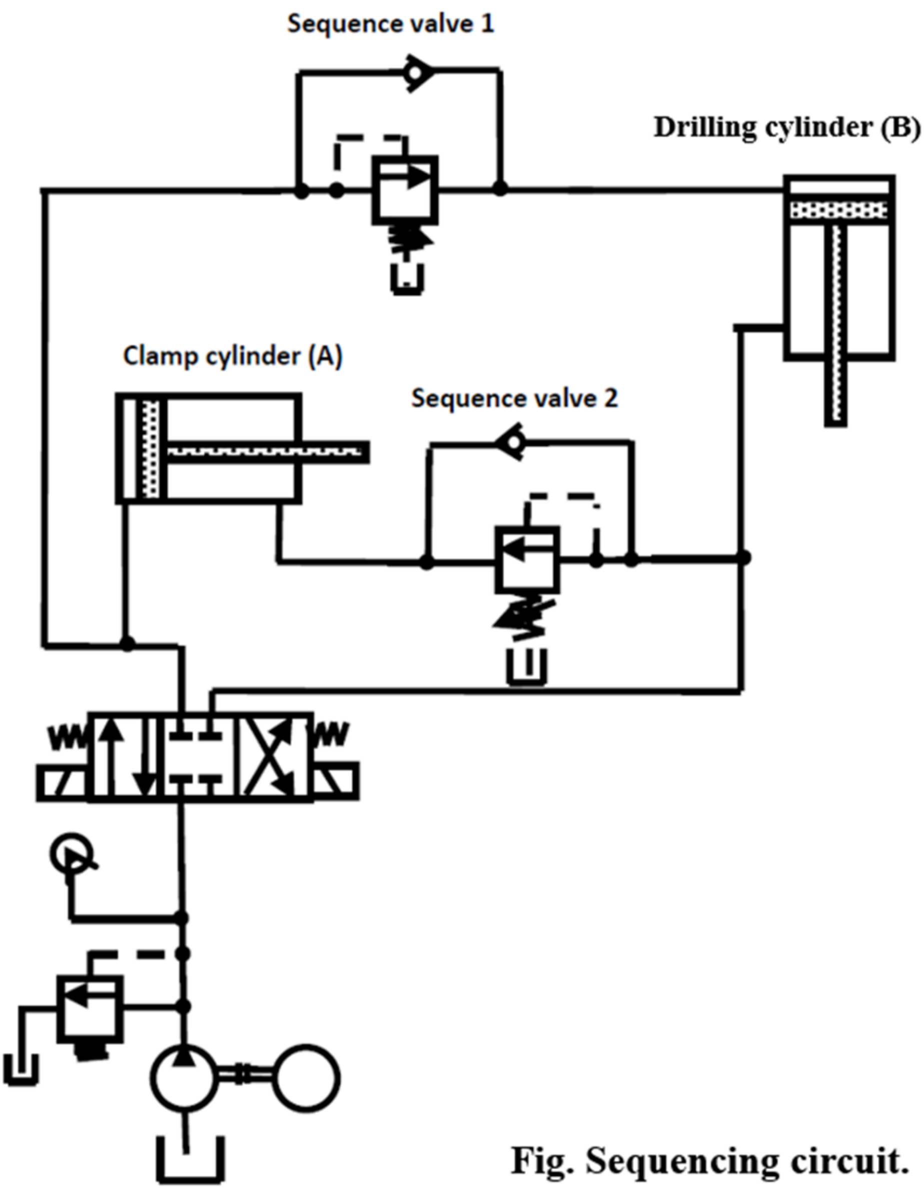

Fig. Sequencing circuit.

- When the DCV is positioned to its right-envelope mode (actuated right), hydraulic fluid first flows to the drilling cylinder (B).
- Sequence valve 1 is set to open only after cylinder (B) is fully retracted, allowing fluid to flow to the clamp cylinder (A).
- Once the drilling cylinder (B) has fully retracted, pressure builds up and opens Sequence valve 2, causing the clamp cylinder(A) to retract.
- This ensures the drilling operation is completed before the clamp releases the workpiece.
- When the DCV is positioned to its left -envelope mode (actuated left), **Cylinder A** is used as a clamp cylinder and **cylinder B** as a drill cylinder.
- **Cylinder A extends** and clamps a work piece.
- **Then cylinder B extends** to drive a spindle to drill a hole.
- **Cylinder B retracts** the drill spindle and then **cylinder A retracts** to release the work piece for removal.

Application

- This sequencing ensures safe and precise automated processes in hydraulic press or forming equipment, where the exact sequence of operations is critical for product quality and equipment safety.
- By using sequence valves, the system logic is hydraulically controlled without external sensors or electrical controllers.

MAINTENANCE OF HYDRAULIC SYSTEM

The primary objective of hydraulic system maintenance is to ensure the reliable transmission of power, maximize component lifespan, and prevent catastrophic failures. System failures are rarely sudden; they are typically the culmination of progressive component degradation, most often driven by fluid contamination or thermal breakdown.

1. Maintenance Strategies

Effective maintenance protocols generally fall into three theoretical categories:

- **Reactive Maintenance (Breakdown):** Operating the system until a component fails. This is highly inefficient in industrial and robotic applications due to unplanned downtime and secondary damage to adjacent components.
- **Preventive Maintenance (PM):** A time-based or cycle-based approach where components (like filters, fluid, and seals) are replaced at regular intervals regardless of their current condition.
- **Predictive Maintenance (PdM):** A condition-based approach utilizing diagnostic tools to predict when a failure might occur. This is the most advanced strategy, relying on data such as oil analysis, vibration monitoring, and thermography.

2. Fluid Integrity and Contamination Control

The hydraulic fluid is the lifeblood of the system, acting as a power transmission medium, lubricant, heat transfer agent, and sealant. Over 75% of hydraulic system failures are attributed to fluid contamination.

- **Particulate Contamination:** Solid particles (metal shavings, silica, elastomer wear) act as abrasives. They cause clearance expansion in pumps and stiction in directional control valves.
- **Water Contamination:** Water ingress destroys the fluid's lubricity, promotes oxidation, and accelerates component rust. It can also lead to fluid aeration and cavitation.
- **Air Contamination:** Entrained air leads to a spongy system response, increased operating temperatures, and severe pump damage through cavitation.

- **Thermal Degradation:** Operating above the fluid's rated temperature breaks down additive packages and increases the oxidation rate, forming sludge and varnish that clog orifices.

3. Component-Level Maintenance Protocols

Pumps and Motors

Pumps generate flow, not pressure (pressure is resistance to flow). Maintenance focuses on ensuring volumetric efficiency.

- **Cavitation Monitoring:** Occurs when the fluid's localized pressure drops below its vapor pressure, forming bubbles that violently implode against metal surfaces. It requires checking for inlet restrictions (e.g., clogged suction strainers) and listening for a characteristic "marbles in the pump" noise.
- **Aeration:** Similar to cavitation but caused by outside air entering the suction line. Maintenance involves inspecting suction line joints and shaft seals.

Filters and Strainers

Filters are classified by their beta ratio (filtration efficiency) and micron rating.

- **Placement:** Maintenance strategies depend on location (suction, pressure, or return line filters).
- **Bypass Valves:** Filters must be changed before the pressure differential forces the bypass valve open, which would allow unfiltered fluid to circulate freely.

Reservoirs

The reservoir provides volume for thermal expansion, dissipates heat, and allows contaminants to settle and air to escape.

- **Breather Caps:** Desiccant breathers must be maintained to prevent atmospheric moisture and dust from entering as the fluid level fluctuates.
- **Baffle Plates:** Regular cleaning of the reservoir interior is required to remove accumulated sludge that baffle plates intentionally trap.

Actuators (Cylinders)

Linear actuators convert fluid power into mechanical force.

- **Rod Seals and Wipers:** Wipers prevent environmental ingress, while seals prevent fluid egress. Maintenance involves inspecting the rod for scoring, which indicates bearing wear or abrasive contamination tearing the seals.

Valves

Directional, pressure, and flow control valves rely on tight internal clearances (often measured in microns).

- **Stiction:** Valves sticking due to varnish build-up or particulate silting. Maintenance involves ensuring fluid cleanliness and occasionally disassembling and cleaning valve spools.

4. Key Diagnostic Indicators

When outlining troubleshooting theory, the "Big Three" indicators of impending hydraulic failure are:

1. **Abnormal Noise:** Indicates aeration, cavitation, or mechanical wear in the pump/motor coupling.
2. **Excessive Heat:** Indicates internal leakage (fluid moving from high to low pressure without doing work generates heat), highly restrictive filters, or a malfunctioning heat exchanger.
3. **Slow/Erratic Operation:** Indicates a loss of volumetric efficiency (pump wear), cylinder seal bypass, or aerated fluid.
