CATERPILLAR®

SERVICE TRAINING

BASIC HYDRAULIC SYSTEMS

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BASIC HYDRAULIC SYSTEMS

Purpose:

This handout covers the most common questions about Cat hydraulic systems. It will explain the different hydraulic systems, components, and methods of operation.

Fluid

Oil

Oil is a light, viscous liquid used as a lubricant or for power transfer in a hydraulic system. Most common oils are refined from naturally occurring crude oil. The properties of the oil can be changed either in the refining process or by using additives. Like most other liquids, oil is a virtually incompressible substance. Therefore, it transmits power instantaneously in a hydraulic system. The primary functions of oil in a hydraulic system include:

- Power transmission
- Lubrication
- Sealing
- Cooling

Viscosity

Oil becomes thin as the temperature rises and thickens as the temperature lowers. If the viscosity of the oil is too low, the oil may leak past seals and joints. If the viscosity is too high, sluggish operation may be the result and extra power is needed to push oil through the system. Viscosity of oil is expressed by the Society of Automotive Engineers (SAE) numbers 5W, 10W, 20W, 30W, 40W, etc. The higher the viscosity number, the thicker the oil. Most hydraulic systems use 10W oil.

Petroleum Oil

Petroleum oil is the most common type of oil used in hydraulic systems. It is refined from naturally occurring crude oil found in the earth's crust. It can maintain a constant volume under high pressure, compressing only 1% for every 2000 psi. The molecular chains of petroleum oil are random in length. This means that at extreme high or low temperatures, petroleum oil can break down in the system over a long range of time.

Synthetic Oil

Synthetic oil is a lubricant that is manufactured without the use of crude oils for base stock. The process of making synthetic oil involves chemical reactions with specific materials to produce a compound with planned and predictable properties. Synthetic oils are specifically blended with a higher viscosity index than petroleum oils. Viscosity index is a measurement of a fluid's change in thickness depending upon changes in the temperature. This enables synthetics to operate in extreme heat and cold better than petroleum oils. The molecular chains in synthetic oil are consistent in length, enabling a close estimate to be made about the properties of synthetic oil. Synthetic oils have no significant advantage in normal temperature ranges or at standard change intervals.

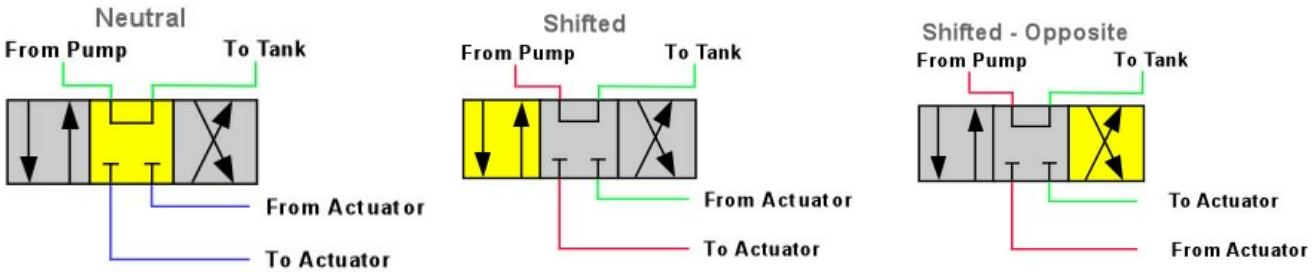
Biodegradable Oil

Biodegradable oil is a fluid based on biodegradable vegetable oil. It is recommended when hydraulic machines have to operate in environmentally sensitive areas such as forests, parks, golf courses, lakes, and agriculture. If spilled, biodegradable oil is able to biodegrade and will not cause damage to the soil, water, environment, or nature. The fluid properties of biodegradable oil are typically inferior to most petroleum and synthetic based oils.

VALVES

Directional Control Valve

A directional control valve directs the supply of oil to an actuator. A directional control valve consists of a body with internal passages, which are connected and disconnected by a moveable valve spool. Inside of the valve is the valve spool. The valve spool consists of lands and grooves. The lands block oil flow through the valve body, while the grooves allow oil to flow around the spool and through the valve body. There are two basic types of directional control valves; open center valves and closed center valves.



Open Center Valves

Open center valves permit oil to flow through the valve at all times. In NEUTRAL the open center passage allows oil to flow from the supply back to the tank at low pressure. When the valve is shifted, oil flows from supply to an actuator. The returning oil from the actuator flows back through the valve to the tank. The valve can be shifted in the opposite direction, allowing it to be supplied to the opposite side of the actuator.

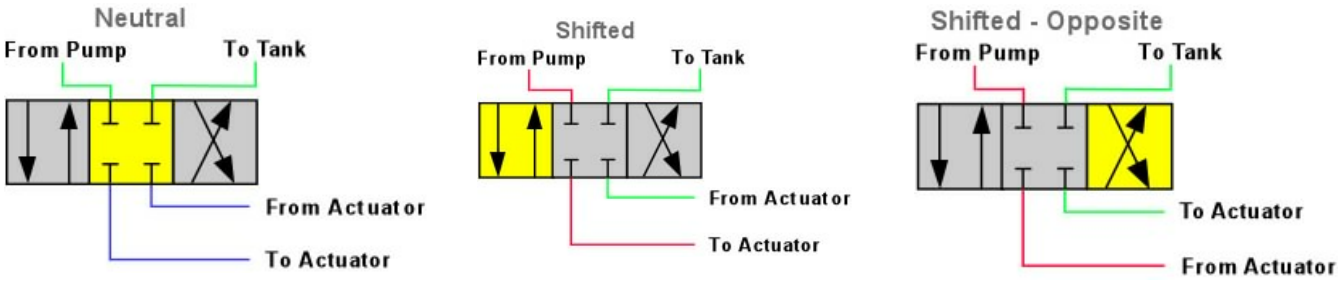
Open center hydraulic systems are always supplying a relatively high flow. This enables the hydraulic system to quickly respond when the valve is shifted.

Advantage:

- Fast response

Disadvantage:

- Partial shift causes partial flow to the tank and the actuator, which generates more heat
- Control may not be as precise
- Typically requires a larger oil cooler



Closed Center Valves

Closed center valves operate similar to open center valves, except in NEUTRAL. Closed center valves block the flow from the pump to the tank in NEUTRAL. When the valve is shifted oil flows only to the actuator with a full or partial shift. When the valve is centered, flow through the valve stops. These valves are typically used with a variable displacement pump to provide flow on demand.

Advantage:

- Flow only to circuit activated
- Generates less heat than open center valves
- More precise flow control

Disadvantage:

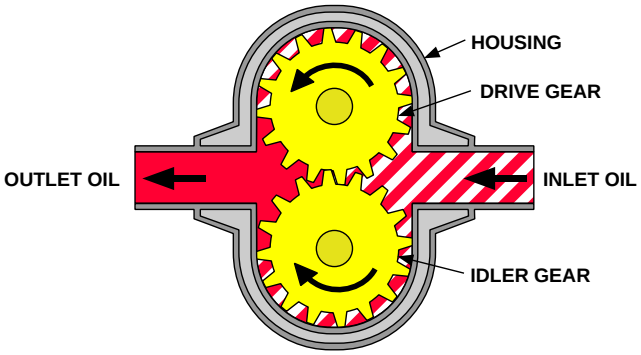
- Requires high flow relief valve or variable displacement pump
- Slower response when activated

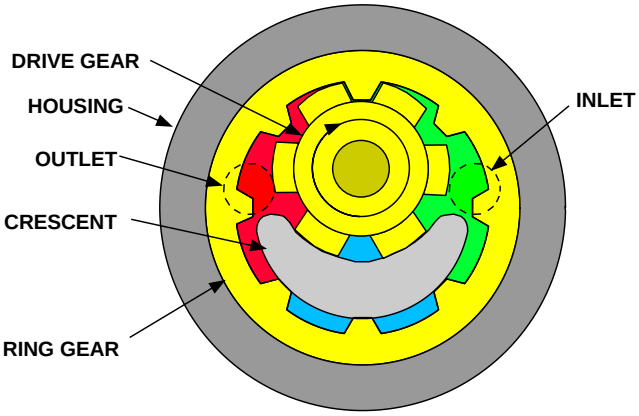
HYDRAULIC PUMPS

Hydraulic pumps are used to create flow of the oil in a hydraulic system. Various designs are used for pumps including:

- Gear
- Vane
- Gerotor
- Piston

All pumps produce flow. Pressure is created as a result of system restriction.





Gear Pumps

A gear pump develops flow by carrying fluid between the gear teeth and the housing. There are two types: external and internal. External gear pumps have two gears in mesh fitted inside a housing. Internal gear pumps (A.K.A. crescent pumps) also use two gears, but one gear rotates inside the other gear.

Advantages:

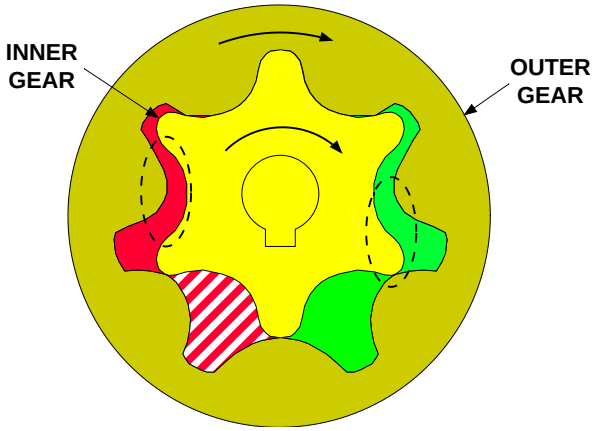
- Simpler system
- Compact design
- Handles debris well
- Long life
- Low cost

Disadvantages:

- Fixed displacement
- Input speed must be increased to get more flow output
- High horsepower draw

Where Used:

- Engine oil pumps
- Transmission pumps
- Lower pressure hydraulic systems



Gerotor Pumps

A gerotor pump is similar to an internal pump except that the inner gear sets inside the outer gear, and the outer gear turns slower than the inner gear on some designs. Other designs have a fixed outer gear and the inner gear walks around in the outer gear (Also known as a hand-metering unit).

Advantages:

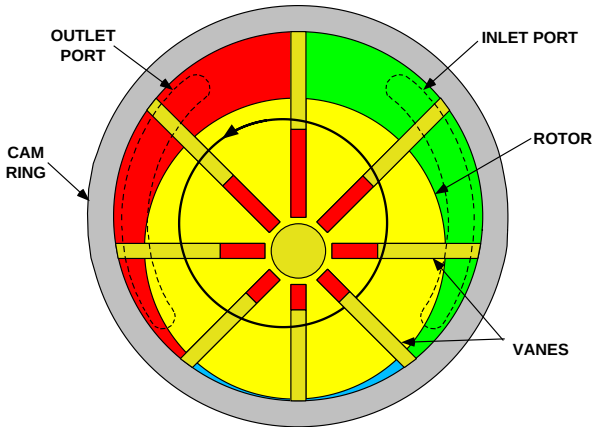
- Compact design
- Low cost

Disadvantage:

- Fixed displacement
- Input speed must be increased to get more output
- Lower pressure range than other pumps

Where Used:

- Steering systems
- Some engine oil pumps



Vane Pumps

The operation of a vane pump works by a rotor driven by a drive shaft that turns inside an oval cam ring. Vanes are fitted to the rotor slots and follow the surface of the ring as the rotor turns. The fluid is forced between the vanes and is carried out to the other side of the pump. Vane pumps are either fixed or variable displacement. Variable displacement pumps are not as robust as fixed displacement pumps and are seldom used in mobile hydraulic applications. Fixed displacement pumps that use two inlet and outlet ports are balanced, which increases the pump life.

Advantages:

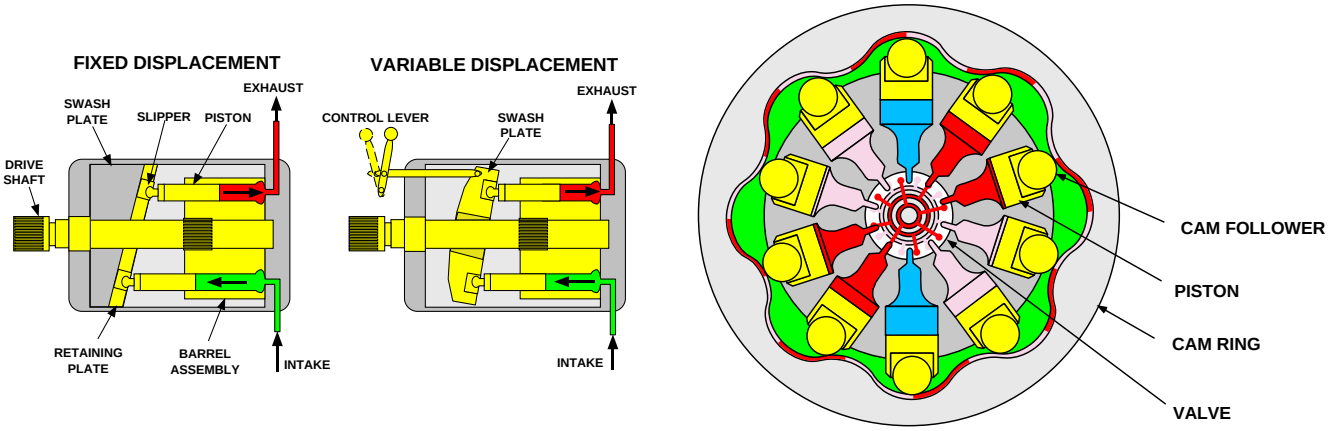
- Versatile design
- Unbalanced pumps are able to be variable displacement pumps
- Quiet

Disadvantages:

- Cannot handle as high pressures as other designs
- Does not tolerate contamination well

Where Used:

- Wheel loader hydraulic system
- Scraper hydraulic system



Piston Pumps

Piston pumps operate by a piston reciprocating in a bore as the pump rotates. The piston draws fluid in as it retracts and expels fluid as it moves forward. Piston pumps can be either radial or axial, and both styles can be fixed or variable displacement. Fixed displacement axial piston pumps operate by using a fixed position swashplate to control the output of the pistons. Variable displacement axial piston pumps vary displacement by varying the angle of the swash plate. Radial piston pumps are typically variable displacement and vary their displacement by moving a reaction ring to increase or decrease piston travel.

Advantages:

- Capable of high speeds and high pressures
- Variable displacement capability
- Reduced horsepower draw

Disadvantages:

- More complex than vane or gear pumps
- Tightly machined surfaces demand clean hydraulic fluid
- High initial cost
- Does not tolerate contamination well

Where Used:

- Hydraulic Excavator hydraulic system
- Track Type Loader Hydrostatic drive system
- Backhoe Loader hydraulic system

HYDRAULIC MOTORS

Hydraulic motors closely resemble hydraulic pumps in construction. They basically work the opposite of a hydraulic pump. Instead of pushing on the fluid as the pump does, hydraulic motors are pushed by the fluid and develop torque and continuous rotating motion. Hydraulic motors come in a variety of configurations such as:

- Gear Motors – including external and internal gear
- Gerotor Motor
- Vane Motor
- Piston Motor – including axial and radial

HYDRAULIC SYSTEMS

There are several different types of hydraulic systems. These systems differ primarily in the method that is used to control system flow and pressure.

Fixed Displacement System

A fixed displacement system is a simple hydraulic system where the output is proportional to the speed of the pump. Fixed displacement systems use a pump in which displacement cannot be altered. These pumps include gear, vane, fixed displacement piston, and gerotor.

Advantage:

- Simple system
- Low cost
- Responsive

Disadvantage:

- Inefficient
- Limited flow control

Where Used:

- Scraper hydraulic system

Load Sensing Hydraulic System

Load sensing hydraulic systems receive a signal from each implement circuit. The highest implement signal pressure will control the output of the pump. In NEUTRAL there is no signal pressure and the pump is at standby. When an implement is activated, the signal pressure rises, causing the pump to increase flow. The pump will increase flow based upon implement demand up to the capacity of the pump. When system demands exceed pump capacity, the function with the lowest pressure receives the most flow.

Advantages:

- Simple flow control
- Efficient
- Full hydraulic power on demand
- Reduced operator lever effort (for a single circuit)
- Improved fuel economy

Disadvantage:

- Does not account for multiple function flow
- Complex signal network
- No operator sensation

Where Used:

- Backhoe loader hydraulic system

Pressure Compensation

Pressure compensation results in a constant implement speed for a given lever displacement. As the load on a non-compensated circuit varies, the speed of the cylinder will change due to the change in the load. With compensated circuits the implement speed stays the same. In other words, the circuit cycle time is the same with an empty bucket or with a fully loaded bucket. Pressure compensated control valves are typically part of a load sensing system.

Advantages:

- Simple flow control
- Efficient
- Full hydraulic power on demand
- Reduced operator lever effort for multiple, non-piloted circuit operation
- Accounts for multiple function flow in load sensing systems

Disadvantage:

- No proportional flow when flow demand exceeds maximum pump flow
- No operator sensation

Where Used:

- D5M and D6M Track-type Tractors
- D6R, D7R, D8R and D9R with Differential Steering
- D6R and D7R non-Differential Steering
- The loader control valves on Backhoe Loaders

Proportional Priority Pressure Compensated (PPPC)

PPPC hydraulic systems operate similar to LSPC hydraulic systems except PPPC provides flow control to each implement when the request by the operator exceeds the capacity of the pump. This system allows the use of two different implements at the same time while controlling the flow of each implement automatically. For example, when an operator curls the bucket and the stick at the same time and the flow needed exceeds the capacity of the pump, the system automatically slows down both implements proportionally.

Advantage:

- Implement proportional flow control
- Reduced operator lever effort
- Improved fuel economy
- Full power on demand

Disadvantage:

- Complex signal network
- Little operator feel

Where Used:

- Large Hydraulic Excavators (365/385)
- Wheel Hydraulic Excavators
- Motor Graders
- Telehandlers

Negative Flow Control (NFC)

NFC hydraulic systems control pump output with a system flow signal instead of an implement pressure signal. An NFC system uses open center, parallel feed control valves. At standby, a portion of the pump oil flows through the open centers at the control valves. This oil is then supplied to an orifice. This orifice maintains a back pressure in the system, which regulates pump output. When one or more of the control valves are shifted, this NFC signal will be reduced because flow through the open center of the valve is being reduced. This causes the signal to the pump to decrease, and upstroke the pump. NFC is a proportional signal, so less NFC pressure equals more pump output. This system is primarily used in track type hydraulic excavators.

Advantage:

- Fast response
- Pump output based on flow demand
- Improved operator feel
- Simple control system

Disadvantage:

- Open center hydraulics cause heat
- Open center hydraulics have poor individual implement flow control

Where Used:

- Hydraulic Excavators (311-345)

HYDROSTATIC SYSTEMS

Hydrostatic systems take the mechanical rotary output of an engine or electric motor and convert it to a hydraulic source of power using a hydraulic pump. The hydraulic power is converted back to mechanical power using a hydraulic motor. This power can be used to drive a fan, transmission, pump, drive sprocket, wheel, or any other rotary device.

Open Loop Control

Open loop is the most basic form of hydrostatic hydraulic control. In this system the pump inlet oil is completely drawn from the hydraulic tank, the pump output is sent to drive the hydraulic motor, and the return oil from the motor flows back to the tank.

Advantage:

- Works well for traveling at maximum speed

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Disadvantage:

- Does not compensate for changes in system
- Requires a large hydraulic reservoir

Where Used:

- Excavator travel system
- Excavator swing system
- Wheel Excavator travel system

Closed Loop Control

In a closed loop system, the return oil from the motor is sent directly to the pump inlet. Closed loop compensates for load changes and friction, so that motions are more repeatable than with open loop systems.

Advantage:

- Motions are more repeatable than with open loop systems
- Relatively small hydraulic reservoir

Disadvantage:

- Requires a charge pump to keep system full
- Requires some exchange of oil on the return side to dissipate heat from closed loop

Where Used:

- Skid Steer Loaders
- D3G-D5G Track Type Tractors
- Large Track Loader

CONTROL SYSTEMS

Control systems allow the operator to control the various functions of a machine while being stationed in the cab. Control systems can control the movement of the machine either manually or hydraulically.

Manual Controls

Manual controls refer to operator controls in the cab that are directly attached to the implement control valves by a mechanical linkage. When the mechanical linkage is moved by the operator, the valve inside the control valve assembly is shifted, which then moves the implement controlled by that valve.

Advantages:

- Provides the best operator feel
- Simpler system

Disadvantages:

- Higher operator fatigue

Pilot Controls

Pilot controls give the operator better control with less effort, which results in less operator fatigue. Pilot control valves send a low-pressure hydraulic signal from the control levers to the implement control valve spools. The implement control spools control the flow of high-pressure oil. This allows the operator to easily move the levers to control pilot oil rather than moving a direct lever on the control valve.

Advantages:

- Less operator fatigue
- Smaller operator controls

Disadvantage:

- Less operator feel

Electro-hydraulics

Electro-hydraulic control allows more accurate and faster control of machine implements. An electro-hydraulic system sensor or switch sends an electronic signal to an electro-hydraulic solenoid valve. The valve processes the information received electronically and outputs that information hydraulically. A good example would be traction control. A traction control system has a sensor on each wheel that senses wheel speed. When one wheel starts to spin, the sensor sends a signal to the electro-hydraulic valve, which supplies fluid pressure to the brake on the slipping wheel.

Advantage:

- Better control

Disadvantage:

- More complex control system
- No operator feel

Where Used:

- Transmission controls
- Telehandlers

OTHER HYDRAULIC TERMS

Regeneration

Regeneration is a hydraulic circuit technique that takes hydraulic fluid from one end of the cylinder and causes it flow to the other end of the cylinder to combine with the pump flow and increase speed of the movement, while decreasing the load on the system. Regeneration can also be referred to as the "Quick drop" function.

Advantage:

- Faster speeds

Disadvantage:

- More complex hydraulic system

Where Used:

- Hydraulic Excavators
- Track Type Tractors
- IT machines
- Backhoe Loaders with IT linkage
- Tractor Scrapers

Series Flow Hydraulic System

Series hydraulic flow supplies oil to the first control valve in the main control valve group. The valves are open center directional control valves in the main control valve group, so the supply oil flows through the first control valve to the second and so on before returning to the tank.

In a series directional control valve, when the valve is shifted the return oil from the circuit becomes supply oil to a circuit downstream. This feature allows multiple circuits to function at the same time. Currently, only a few machines are equipped with valves of this type and usually only for a single circuit for only one position of the directional spool. For example, this feature allows 953C-973C Track Loaders to dump and raise the bucket at the same time.

Caterpillar uses interrupted series directional control valves rather than series directional control valves. When fully shifted, these valves direct return oil to the tank and not to a valve downstream. This action prevents multiple valves from functioning at the same time. When a valve is only partially shifted, supply oil not used by the first activated valve is available for downstream valves. This feature provides flow priority for one circuit over another. Some Caterpillar wheel loaders use this type of system to allow tilt to have flow priority over the lift circuit. When the operator goes into the pile, he will typically put the lift control lever into detent for full lift and then modulate the tilt control valve to maximize the load in the bucket. With most of the flow going to the tilt valve the loader arms will move slowly until the bucket is out of the pile, at which time the loader arms raise the bucket rapidly to the maximum height in preparation for dumping the load into a haul truck.

Advantage:

- Can increase machine performance for some applications

Disadvantage:

- Multiple valve operation can be restricted

Where Used:

- 931-935 Traxcavator (series-type)
- 918F-928F Wheel Loaders (interrupted series-type)
- 924G-938G Wheel Loaders (interrupted series-type)
- 950G-972G Wheel Loaders (interrupted series-type)
- 933C-939C Track Loaders (tilt valve - Rackback and Dump)
- 953C-973C Track Loaders (tilt Valve - DUMP only)

Parallel Flow Hydraulic System

Parallel valves may be either open or closed center valves. Parallel hydraulic flow supplies oil to all valves in the main control valve group at the same time. This allows each valve to receive flow regardless of the position of other valves. When two valves are fully activated simultaneously, the oil will flow to the function that requires the least amount of pressure. No priority is given to any valve or function.

Advantage:

- Can operate two or more valves at once without flow loss to downstream valves

Disadvantage:

- The function that requires the lowest pressure will receive the most flow unless it is a PPPC system. Other circuits will operate slower.

Where Used:

- Motor Graders
- Telehandlers
- Backhoe Loaders
- D4H/D5H and D5M/D6M TTT
- D3C-D5C Track-type Tractors
- D3G-D5G Track-type Tractors
- 902-908 Wheel Loader
- 914G/IT14G Wheel Loader

Priority Flow Hydraulic System

Priority flow ensures that a function receives flow before flow is directed to other non-priority functions. This is typically used for special work tools to ensure optimum operation, or to steering/brake systems for safety reasons.

Advantage:

- Safety
- Critical circuits receive flow before all other circuits

Disadvantage:

- System is more complex

Where Used:

- Backhoe steering system
- Telehandler steering system
- Wheeled hydraulic excavator tool control, steering, and brake functions