

Hydrostatic transmission design – Tandem closed-loop circuit applied on a forestry cable carrier

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Abstract: This article describes a way to design a hydraulic closed-loop circuit from the customer's book of specifications. After explaining the details of the needed design, a complete study is performed in order to provide a range of products from Poclain Hydraulics, composing the right solution for the system. Heavy-duty high torque motors, closed-loop pumps, control valves, electronic controllers: all these components have to be integrated on the machine to ensure an efficient, innovative and safe control of the load.

The application presented here is a mobile cable carrier, designed to carry logs from one point to another along a 250 m track. The machine is based on a combination of 3 winches, each one hydraulically controlled, working together in order to transport the loads on any ground configuration. Each winch is actuated by a high torque low speed hydraulic motor from Poclain Hydraulics, working in direct drive. Each motor is run by an individual pump, each group constituting an independent closed-loop circuit. Additional components, such as static brakes, flushing valves, speed control valves etc., have to be sized and determined as well. The complete system is managed by an electronic controller, specifically programmed according to the customer's need, using a customized software.

The final goal is to get a safe, flexible, and user-friendly machine that the final customer will be able to use in many working configurations, using a simple remote-control interface. According to the movement instruction sent by the user, the electronic controller has to pilot the pumps on its own, taking into consideration the load, speed, temperature values etc. to ensure an optimal cycle time without damaging the components or causing injuries.

Key words: forestry cable carrier, close loop circuit, heavy duty hydraulic motor

■ 1 Working conditions and environment

The machine can be set up in any place that a standard agricultural tractor can access. This implies a compact design in order not to make it wider than the tractor or too long, which would limit its capacity to be installed anywhere – *Figure 1*.

The main cable line can be up to 250 m long, following a slope from 0° to



Figure 1. Working environment

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70° steep. At each end, the cable is secured by several anchoring cables which distribute the main cable pulling force into the ground. It is stretched out during the installation of the machine in the working area, and then remains unmoving during the use of the machine.

Two auxiliary cables are used to move the trolley uphill or downhill. In some cases, the slope is not regular: some parts of the slope are flat while some are steeper, sometimes holes can be in the way, meaning that the log is for a while fully in the air, etc. Consequently, the force in the pulling cables can vary widely for a constant payload, depending on the configuration of the ground. These varying values of force will be transferred to the winches, and they will strongly affect the torque which will have to be generated by the actuators.

The machine must be able to work in quite difficult conditions. Temperatures from -20 °C to +40 °C, 12 hours / day without stops, etc. are factors that have to be taken into account for the design. The control of the temperature of the oil is a key factor on this application.

In terms of safety, the load must be permanently under control to prevent any accident. In case of severe failure of any hydraulic components, the load must be stopped. Special care must be taken on the electronic monitoring of the system.

■ 2 Components quick sizing

2.1 Hydraulic motors

The use of a hydraulic dual-displacement shaft motor with integrated bearing support and exchange valve is shown in *Figure 2*.

TORQUE:

For compactness and cost reasons, the best way to actuate the winch drums is to use low speed high torque motors. Assembled directly on the drum, they enable the user not to use any gear-box or intermediate parts which would decrease the mechanical efficiency of the



Figure 2. Hydraulic dual-displacement shaft motor with integrated bearing support and exchange valve bearing

transmission. "Came-lobe" radial pistons motors from Poclairn Hydraulics are able to generate up to 95000 Nm, and are designed to match the requirements of this application in terms of torque capacities.

SPEED:

Because of the high torque capability of the motors, an in-line gear box is not mandatory, and consequently, the motors will not have to spin very fast during the operation of the machine. Nevertheless, when there is no load, the trolley on which logs are fastened must be able to reach the next log quite fast to save time and increase the general efficiency of the machine. For that reason, hydraulic motors can be equipped with a specific shifting spool which permits to divide the displacement of the motor by 2. Consequently, for a constant flow, the motor can spin twice as fast as when the machine is not loaded.

BRAKING:

For safety and accuracy reasons, all winches must be immobilized when they are not spinning. Internal leakages of the hydraulic components impose the use of a mechanical brake somewhere in the transmission. Otherwise, drums could slowly move even when there is no flow sent through the hydraulic motors. Indeed, because a small quantity of oil is permanently leaking between the internal components of the motors, maintaining a constant static pressure into their return lines to immobilize their transmission shaft is not possible without flow.

This braking function can be achieved by a static multi-disc brake assembled on the rear side of the hydraulic motors. It cannot be used dynamically, but provides a braking torque twice as high as the maximum torque of the motor.

EXCHANGE:

Different solutions can be applied to maintain the temperature at an acceptable level. A very large tank or very large cooler (air/oil, water/oil), an auxiliary cooling circuit, exchange valves etc. All of them have a different impact on the compactness of the machine, the dissipated heat, the efficiency of the cooling, the cost, etc.

An efficient and space-effective way to cool down the circuit is to combine several options on a lower scale: medium-sized tank, medium-sized air/oil exchanger, and oil-shuttle valves to take some of the hot oil off from the circuit and send it directly to the cooler. The missing oil is compensated by the charge pump which sends some fresh oil from the tank.

The exchange valve can be fully integrated into the hydraulic motor, sending some hot oil from its low pressure side to the cooler through its drain.

MOUNTING:

The easiest and most compact way to assemble the motor on the drum is to use its own internal bearing support which will directly support the winch on one side. Only one additional bearing support is necessary on the opposite side.

2.2 Closed-loop pump

The working principle of the machine imposes the followings:

- Each motor must work totally independently.
- Each motor must be able to spin from 0 to max speed proportionally, in both directions.
- The load must be hydrostatically braked.

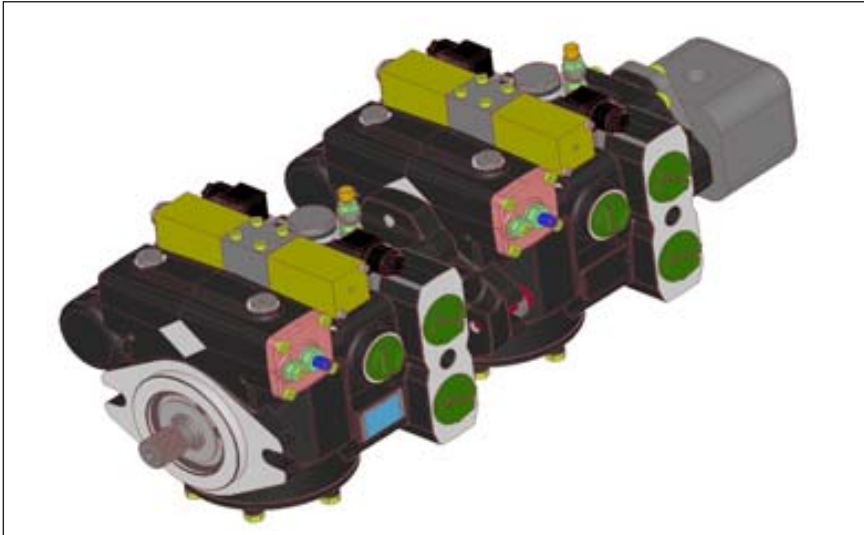


Figure 3. Closed-loop tandem pump with additional gear-pump for auxiliary functions

These requirements imply two different solutions:

- Open-loop circuit, using probably one big pump and some valves to control the speed of the motors, their torque, their braking capacity, etc.
- Closed-loop circuit with two independent variable displacement pumps, each one controlling one motor. No valves. All functions can be performed by the pumps.

The chosen pump from the PM series can work with a pressure of up to 350 bar and can join all the components needed in the circuit into one single compact design: charge pump, high pressure relief valves, charge relief valve, electro-proportional control, charge filter, etc. This dimension feature is particularly interesting in terms of integration on

the machine.

Because there is a need to control both motors with two independent, varying flows, two pumps will be used, assembled as a tandem – *Figure 3*.

2.3 Electronic control unit (ECU): SmartDrive™ Easy Plus

The ECU is the interface between the control device of the machine (remote control) and the pump – *Figure 4*. On this machine, its functions are:

- to control the displacement of both pumps,
- to monitor all values sent by the sensors located on the machine,
- to compare input values from the sensors and regulate the output control currents of the pumps,
- to apply automatic safety sequences in case of trouble (automatic stops, limp mode etc.),
- to be able to work without being influenced by external electric interferences.

To fulfill specific customer requirements the ECU is working with customized software,

adapted to the customer need, created by Poclairn Hydraulics Electronic department.

The basic hydraulic scheme of a closed-loop circuit with the described components is shown in *Figure 5*.

■ 3 Radial pistons motor in closed loop

The most important functions of the radial piston engine are presented in detail below. A radial piston motor operating within a closed-loop circuit is shown in *Figure 6*.

Charge function: A permanent charge flow coming from the charge pump located in the main pump compensates leakages in the circuit and maintains a permanent charge pressure in the circuit. Thanks to this pressure, all pistons remain in contact with the circular cam.

Main flow: The variable flow coming from the main pump supplies only a certain quantity of piston chambers. Consequently, these “high pressurized pistons” tend to go out of the cylinder block. Due to the geometry of the lobe located above the rollers (slope), the motor spins by a few degrees.

This rotation will position another group of cylinders in front of the high-pressure supply, which will generate another rotation, and so forth, while the previous group is linked to the charge pressure.

Motor’s hydrostatic control: The advantage of the closed-loop configuration is to be able to manage the motor speed and its ability to brake simply by taking advantage of the pump displacement, without using any additional components.

Disposing of a “return line” from the motor to the pump allows the pump to brake the motor by maintaining a back pressure behind it. The flow is not free to increase without generating a resistance from the motor. It is regulated by the pump. During a deceleration sequence, the more the motor tends to accelerate be-



Figure 4. SmartDrive™ Easy Plus ECU

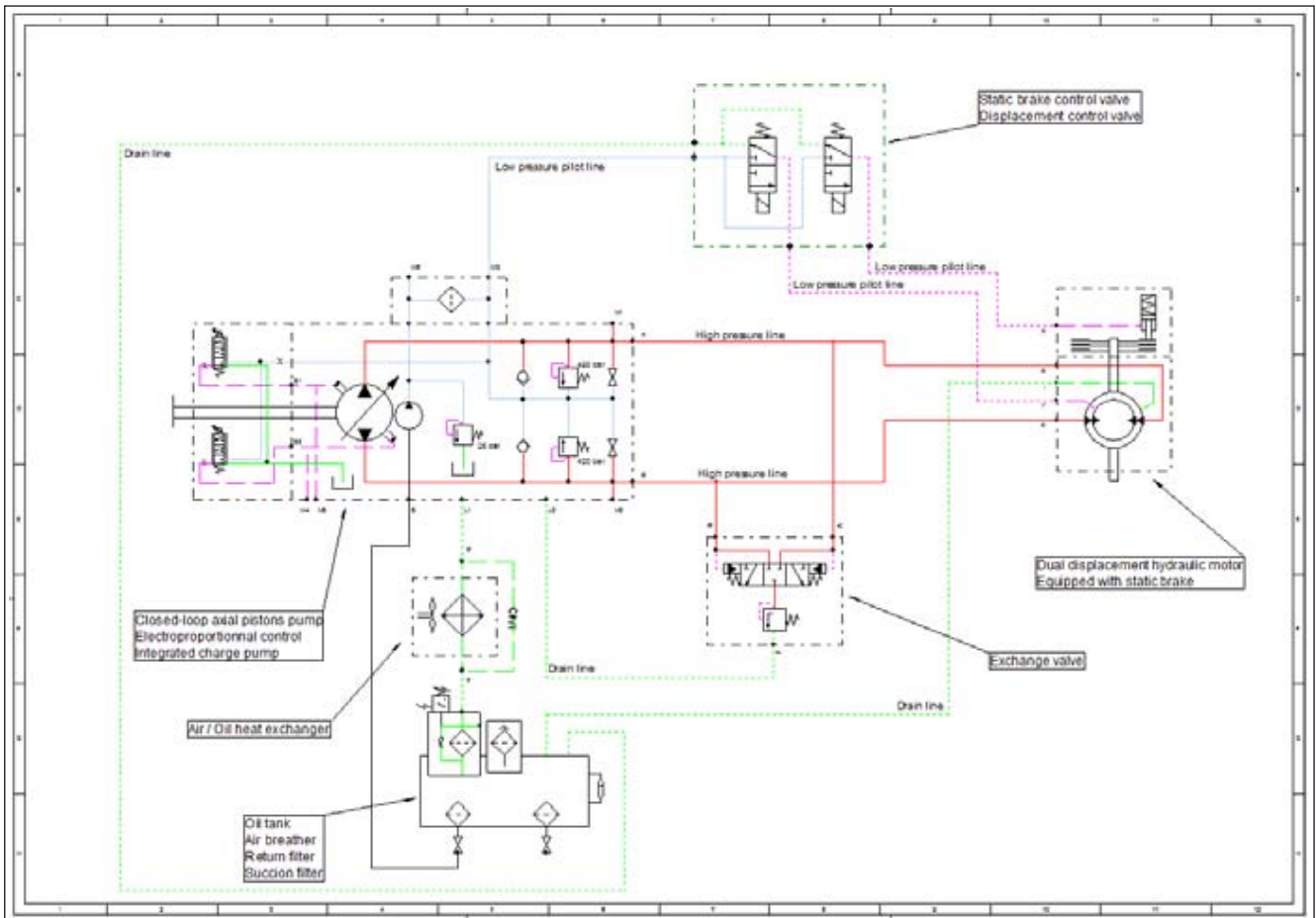


Figure 5. Theoretical hydraulic schematic of a closed-loop circuit

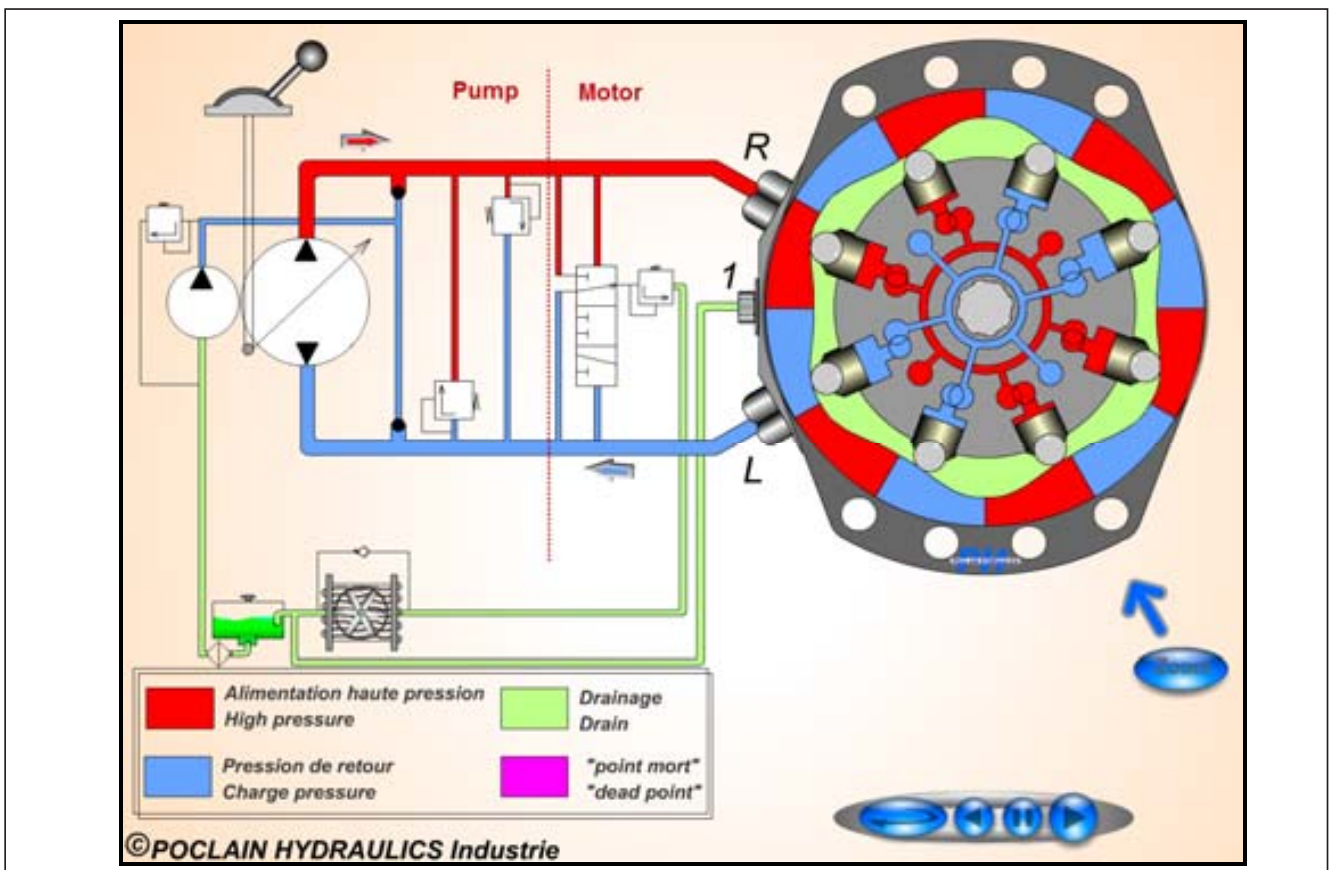


Figure 6. Basic working principle of a radial pistons motor in closed loop

cause of the inertia of the load, the more the pressure will increase in the return line. As long as the displacement of the pump remains constant, the flow will not increase. It will remain the same, and consequently, the speed of the motor will be under control.

Drains – flushing: Each component of the circuit must evacuate the oil coming from the internal leakages appearing between the fixed and mobile parts composing it. This limited flow generally escapes the components through the drain line to the tank. In the case of an absence of the drain, the pressure inside the case of the components increases and damages it after a while.

To save space and piping work, the oil shuttle valve can be implemen-

ted directly into the hydraulic motor. This is the case on this application. The hot oil flow coming from the valve is evacuated with the leakages through the drain, then goes on through the cooler and discharges down into the tank.

■ 4 Conclusion

In terms of compactness, cost-effectiveness, and quantity of components, a closed-loop hydraulic circuit is for sure the best choice to drive hydraulic motors, especially on this kind of applications where a strong hydrostatic braking capability is required. All the piloting and safety organs are located in the pump, allowing a complete proportional and bi-directional control of the motors without any additional hydraulic components.

On the other hand, integrated brakes, flushing valves and dual-displacement spools in the hydraulic motors allow the user a wider range of possibilities.

The ECU, adaptable to the customer's needs, ensures a safe and complete control of the application with the ability to adapt the behavior of the machine by monitoring sensor values.

All the hydraulic components supplied by Poclain Hydraulics (pump, motors, valves, ECU) are implemented on the machine within a compact and optimal design to match the space requirements, allowing the user to use it in any working area. ■

Snovanje hidrostatičnega tandemskega pogona za mobilno gozdarsko žičnico

Razširjeni povzetek

Prispevek opisuje pristop k snovanju hidrostatičnega tandemskega pogona primerne za uporabo na mobilni gozdarski žičniški napravi, delujoči kot zaprti hidravlični krogotok, zasnovan skladno s postavljenimi zahtevami naročnika. Rešitev predvideva uporabo hidromotorjev visokega navora, črpalko delujočo v zaprtem krogotoku, ter uporabo ustreznih ventilov in elektronskega krmiljenja. Vse vgrajene komponente morajo zagotavljati učinkovito in varno delovanje ter nadzor nad obremenitvijo.

Predstavljena rešitev pogona je primerna za uporabo na mobilni gozdarski žičniški napravi, namenjeni za transport hlodov z ene točke na drugo, med seboj oddaljeni do 250 m. Naprava temelji na kombinaciji 3 hidravlično krmiljenih vitlov, ki omogočajo prevoz tovora ne glede na konfiguracijo terena. Vsak vitel poganja počasi tekoči hidromotor visokega navora proizvajalca Poclain Hydraulics delujoč kot neposredni pogon. Vsak hidromotor napaja posebna črpalka, skupaj z motorjem delujoča v zaprtem krogotoku. Dodatne komponente, kot so statične zavore, izpiralni ventil, ventil za krmiljenje hitrosti, so ustrezno dimenzionirani in zagotavljajo izvajanje vseh potrebnih funkcij. Celoten sistem je upravljan z elektronskim krmilnikom, posebej programiranim glede na potrebe kupcev, z uporabo namenske programske opreme.

Končni cilj rešitve je dobiti varno, prilagodljivo in uporabniku prijazno napravo, ki jo lahko končni uporabnik uporablja v različnih delovnih konfiguracijah, s pomočjo preprostega daljinskega krmilnega vmesnika. V skladu s poslanimi zahtevami o hitrostih in gibanju bremena, ki ga proizvajalcu pošlje uporabnik, elektronski regulator samodejno in optimalno uravnava črpalko, v odvisnosti od prisotne obremenitve, hitrosti, vrednosti temperature, Tako je zagotovljen optimalni čas delovnega cikla, ne da bi poškodovali komponente ali bi prišlo do kakršnih koli poškodb upravljalca naprave.

Ključne besede: gozdarska žičnica, zaprti krogotok, hidromotorni pogon z visokim momentum

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We wish to thank the company TAJFUN d.o.o for allowing POCLAIN to mention their cable carrier in this paper.